Trends in technology, trade and consumption likely to impact on microbial food safety

T. E. Quested[1], P. E. Cook[1], L.G.M. Gorris[2,*], and M.B. Cole[3]

1. Food Standards Agency, 125 Kingsway, London, WC2B 6NH, United Kingdom.
2. Unilever, Safety & Environmental Assurance Centre, Sharnbrook, Colworth Science Park, MK44 1LQ, United Kingdom; European Chair in Food Safety Microbiology, Laboratory for Food Microbiology, Wageningen University, Wageningen, The Netherlands.
3. National Center for Food Safety and Technology, Summit, Illinois, 6502, U.S.A. (new address since 1-1-2010 to be footnoted: Food Science Australia, North Ryde, Australia)

Corresponding author:

Leon G.M. Gorris, Unilever, Safety & Environmental Assurance Centre, Sharnbrook, Colworth Science Park, MK44 1LQ, United Kingdom.

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Abstract

Current and potential future trends in technology, consumption and trade of food that may impact on food-borne disease are analysed and the key driving factors identified focusing on the European Union and, to a lesser extent, accounting for the United States and global issues. Understanding of factors is developed using system-based methods and their impact is discussed in relation to current events and predictions of future trends. These factors come from a wide range of spheres relevant to food and include political, economic, social, technological, regulatory and environmental drivers. The degree of certainty in assessing the impact of important driving factors is considered in relation to food-borne disease. The most important factors driving an increase in the burden of food-borne disease in the next few decades were found to be the anticipated doubling of the global demand for food and of the international trade in food next to a significantly increased consumption of certain high-value food commodities such as meat and poultry and fresh produce. A less important factor potentially increasing the food-borne disease burden would be the increased demand for convenience foods. Factors that may contribute to a reduction in the food-borne disease burden were identified as the ability of governments around the world to take effective regulatory measures as well as the development and use of new food safety technologies and detection methods. The most important factor in reducing the burden of food-borne disease was identified as our ability to first detect and investigate a food safety issue and then to develop effective control measures. Given the global scale of impact on food safety that current and potentially future trends have, either by potentially increasing or decreasing the food-borne disease burden, it is concluded that a key role is fulfilled by intergovernmental organisations and by international standard setting bodies in coordinating the establishment and rolling-out of effective measures that, on balance, help ensure long-term consumer protection and fair international trade.

1. Introduction.

Though there is little quantitative, concrete evidence that the globilization of food production and marketing has an impact on food safety as it is experienced day-by-day by consumers around the globe, it is very likely that globilization of the food supply as well as other global trends put pressure on the burden of food-borne illnesses in many parts of the world. Technological and infra-structural changes in food supply chains and the ever expanding trade worldwide have changed the pace and distances at which an enormous variety of foods are brought to the consumer's home. While consumers benefit by the product variety available to them, the complexity of the global food supply requires more international collaboration and harmonization of management efforts in order for existing and emerging risks to consumers to be dealt with adequately. It is evident that changes in food production, processing, distribution and consumption at a global scale have impacts well beyond the direct health and wellbeing of consumers. They have major economical, social and environmental impacts that need to be considered as part of global management efforts. Likewise, major differences exist in the impact of global or regional changes between developed, emerging and developing economies.

This paper has been prepared for the conference "Future Challenges to Food Safety", organised by the Dutch Food and Consumer Products Safety Authority (VWA) and the European Food Safety Authority (EFSA), held in Wolfheze, The Netherlands, from 9 to 12 June 2008. It explores current and potential future trends in the foodborne disease burden around the globe as they relate in particular to technology, consumption and trade of certain foods that are likely to impact on microbial food safety. Developments in food technology and significant changes in consumer demand and food trade around the world over the next decade are discussed. To identify trends and underlying drivers, a system-based approach is taken which analyses how different drivers currently impact in broad terms on a system of interacting driving factors representing the food system. In so doing, the impact of potential future events on food technology, international trade and consumption is explored. The paper endeavours to present a global perspective on trends influencing the burden of food-borne disease, while taking many examples from the European Union (EU) and its Member States.

2. Method of Analysis.

2.1. Methods for exploring the future.

The analysis in this paper is underpinned by elements of future studies including horizon scanning and scenario planning methodologies (e.g. Burt and van der Heijden, 2003). The 'environment' surrounding the issue of interest, in this case, consumption and trade of food relevant to the disease burden , is understood by identifying factors that affect this issue, and qualitatively assessing the magnitude of interaction between these factors. In so doing, a system composed of these factors is constructed, with the issue of interest at the centre. The behaviour of the system with time can be analysed, thus identifying key factors (*drivers*) in the operation of the system. This approach helps draw together a wide range of driving factors from many different categories, including social, economic, regulatory, political, technological and environmental drivers (Figure 1).. The inclusion of a broad range of factors put a challenge on the availability of suitable data for the food system build in this study but reduced the number of surprises from parts of the system not normally associated with the issue of interest. Many of the influencing factors are interrelated. For instance, import tariffs may affect availability and price of foods, whereas government campaigns may influence public perception of health benefit. The time-scale of influence varies between factors; some induce gradual change in the system (e.g. demographic developments), whereas others (e.g. a major outbreak of food-borne disease influencing consumer choice) can impart a specific step change.

A key advantage of a system-based approach over, for example, extrapolation of current trends or deterministic modelling, is the handling of uncertainty. Many of the key drivers in the system have large uncertainty associated with them (e.g. oil prices). A system approach allows the impact of the uncertainty stemming from a wide range of factors to be assessed qualitatively, and underpins development of a range of plausible future scenarios, each internally consistent. Furthermore, this approach gives a strong indication of the impact of important drivers, so that, even if their future trajectory cannot be predicted with a large degree of certainty, the driver can be monitored, thus giving forewarning of behaviour in other parts of the system.

2.2. Defining the investigation focus.

The focus of this analysis is the impact of food consumption and trade on the food-borne disease burden. Next to food types, there are elements of the food supply network and consumer behaviour to consider. The latter focus includes trends in foods eaten inside and outside the home, grocery shopping and food-related behaviour (e.g. preparation, storage and consumption patterns).

There are a large number of combinations of food-borne disease agents and food vehicles, and this paper focuses on those foods which have been shown to contribute strongly to the burden of food-borne disease, both in number of cases and severity of illness. Studies have been conducted in a number of countries to assess the burden of food-borne disease and, in some cases, to tease out the contribution of particular pathogens, animal sources, food vehicles or pathogen/food combinations (Batz et al., 2005; Hald et al., 2004; Adak et al., 2005; Kemmeren et al., 2006; Evers et al., 2008).

The food groups contributing to microbial food-borne disease vary with location and time due to, amongst other factors, nature and extent of food contamination, consumer behaviour and consumption patterns. For food-borne disease in England and Wales between 1996 and 2000, Adak et al. (2005) estimated the proportion of cases and deaths relating to food groups using data from the national surveillance database for general outbreaks of infectious intestinal disease. Cases were analysed where a single vehicle of infection was identified by epidemiological or microbiological investigation. These data are reproduced in Table 1. Overall, poultry, red meat such as beef and complex foods (meal dishes consisting of ingredients of various food types in which the precise source of infection was not established) were the two food groups mostly attributed with cases or death. Individual food types which contributed at least 5% of all cases or at least 5% of deaths were identified to be chicken, turkey, eggs, beef, mixed / unspecified red meat and milk. Other red meat categories, shellfish, salad vegetables and rice also contributed to a small but significant proportion while dairy products other than milk, cooked vegetables and fruit did not contribute at all. Outbreaks involving fresh produce, whilst not contributing strongly to the burden of food-borne disease in the dataset presented in Table 1, are attracting international concern with respect to food safety (FAO/WHO, 2008) because of the significance of international trade in these commodities. It is important to emphasise that using outbreak data for food attribution may not adequately reflect the vehicles associated with sporadic cases of illness, which form the bulk of the food-borne disease burden, and may also underestimate the contribution of certain pathogens, e.g. *Campylobacter* or *Toxoplasma* (Batz et al., 2005; Kemmeren et al., 2006).

Relatively high risks for food-borne diseases tend to be associated with those foodstuffs that are least processed, i.e. raw milk, raw or lightly cooked eggs or dishes containing them, raw mince meat (e.g. steak tartare), oysters and to some extent fresh produce. With these foods it is

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particularly important to prevent contamination occurring in the first place, as there are limited options for eliminating the hazard(s) through processing or consumer handling.

Hughes et al. (2007) used data from food-borne disease outbreaks of infectious intestinal disease in England and Wales (1992-2003) to categorise the food vehicle associated with outbreaks. Common pathogen–food vehicle combinations identified were:

- *Campylobacter*: poultry.
- *Salmonella*: poultry, desserts, red meat, eggs.
- *Clostridium perfringens*: red meat, poultry.
- Vero-toxin-producing *E.coli* O157: Red meat, milk and milk products.
- Viruses: fish and shellfish, salad, fruit and vegetables.

It should be noted that this study only considered outbreaks of infectious intestinal disease and that the data did not include outbreaks involving *Listeria monocytogenes*, an important food-borne pathogen in terms of mortality according to the Chief scientist's report (FSA, 2007a). In the few outbreaks in England and Wales, food vehicles for *L. monocytogenes* have included sandwiches, dairy and meat products (McLauchlin et al., 1991; Gillespie et al., 2006). Elsewhere, the prominent role of this pathogen in foodborne illesses has been well recognised (BIOHAZ, 2007; Ontario MoH 2009).

Lynch et al. (2006) examined food-borne disease outbreaks in the USA between 1998 and 2002 and presented data by food vehicle (where known) and pathogen. Whilst some associations are similar to those seen in the outbreak data in England and Wales there were also some differences, such as the relatively high proportion of outbreaks associated with complex foods such as desserts in the UK where it can be difficult to determine the origin of the contamination (Adak et al. 2005).

3. Results.

The consumption level of a specific food type is influenced by a multitude of factors, reflecting the complex role food plays in our lives. To predict future changes in microbial food safety and the disease burden resulting from possibly changing consumption patterns, understanding the interactions between these influences is important. In Figure 2, the key factors identified on the basis of the qualitative analysis in this work are plotted against their likely effect on the burden of foodborne diseases either positively or negatively and also against the certainty of their impact. The following section explores some of these relationships in more detail for the various categories of drivers.

3.1. Political Drivers.

Governments play a critical role in protecting the consumer. However, many countries are poorly equipped to respond to existing and emerging food safety problems. Many lack technical and financial resources, effective institutional frameworks, trained personnel and sufficient information about hazards and risks involved (CSPI, 2005). In many countries political pressures such as civil unrest or particular public health concerns far outweigh concerns about food-borne diseases. Often the desire for a country to grow its economy through food exports is a key driver for investment in food safety infrastructure, though there is a realization that food safety is a prerequisite to support a healthy workforce and developing a successful export business in food.

A governmental agricultural policy can also have a significant impact on consumption patterns. With the harmonisation of a large proportion of food legislation across the European Union (EU), it is of interest to ascertain the fraction of foods that are produced within and outside the EU. The country of origin may have implications for microbiological safety. In addition, the

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balance of imports and exports for a country characterises how trade and food prices are impacted by world food prices.

Considering self-sufficiency of a country or region as the fraction of domestic production divided by domestic use (expressed as a %), the European Union is self-sufficient in most types of meat (Table 2A), the exceptions being sheep and goat meats (Eurostat, 2008a). Furthermore, EU imports and exports of meats and meat preparations represented only ~3% and 8%, respectively, of gross apparent human consumption (Eurostat, 2008b). The figures for the total EU mask very different self-sufficiency levels for Member States. In 2004, Denmark and Greece represented the extremes of meat self-sufficiency with the former producing around 3.3 times the amount it consumed and the latter 0.54 (Llorenes Abando and Martinex Palou, 2006). This illustrates the fact that intra-EU trade is more important than extra-EU trade for most Member States.

3.2. Economic Drivers.

The World Bank estimates that 1.25 billion people live on less than $1/day with 840 million of them suffering under-nutrition or hunger (Thompson, 2007). Some three billion people live on less than $2/day, which generally buys enough calories to offset hunger. As incomes rise from $2 to about $10 per day, people eat more meat, dairy products, fruits, vegetables, and edible oils, causing rapid growth in demand for raw agricultural products. Beyond $10 per day, people buy more processing services: packaging, variety, and luxury forms. Table 3 illustrates the huge potential for poverty reduction in populous key emerging economies and developing countries. The potential market growth for value added products is greatest in countries such as China and India, where there is a huge potential for further population growth as well as poverty reduction. Both population growth and the proportion of presently low-income consumers that are lifted out of poverty will be important determinants of the future global demand for food. The World Bank estimates that the number of people in developing countries living in households with incomes above $16,000 per year will rise from 350 million in 2000 to 2.1 billion by 2030. If there is a 50% increase in the world population plus a 50% increase in broad based economic affluence in low-income countries, then world food demand could double by the year 2050.

Food prices are determined, like prices of all products, by supply and demand. However, unlike many other products the demand for food per capita is, to a large degree, invariant of price for high-income countries. As noted by Tansey (2008), the consumption of most goods (e.g. CDs, shoes) can increase manifold without demand being satiated; the same is not true of food. The effect of food price and income level on food demand can be described by price and income elasticities. *Price elasticity* regarding demand, as opposed to that of supply, for a country is defined by the change in demand due to a change in price. A price elasticity of –1 indicates that an increase in price of, for instance, 1% leads to a decrease in demand of 1%. A price elasticity of zero indicates that demand is independent of price. Similarly *income elasticity* is defined by the change in demand due to a change in income level. Notably, price elasticities are descriptive and therefore not necessarily constant over time; they can evolve to reflect perception, price and availability of food.

If the amount spent on all food is considered, the price elasticity is relatively small (between –0.4 and 0 in high-income countries) (Regmi et al., 2001). Similarly the income elasticity for total food is small in high-income countries (Schmidhuber, 2003). In contrast, income affects food demand strongly in low-income countries. In China and India, where incomes have been experiencing substantial growth recently, overall food demand has risen sharply, with a large impact on global food demand (OECD/FAO, 2007).

However, this is not to say that price or income have no effect on food *choices* in high-income countries. When analysed at the food-type level, price has a significant effect on the demand. Ordinarily, price elasticities are higher where an available substitute exists and the food in question is perceived as a luxury rather than a staple.

Selected price elasticities are shown in Table 2B for large food groups in the United Kingdom (UK; comprising of England, Scotland, Wales and Northern Ireland). In Figure 3, data for Great Britain (GB; comprising of England, Scotland and Wales) show the breakdown for a range of food types. Note that the GB data in Figure 3 are for the mid-income bracket selected as broadly indicative of the population as a whole, whereas the UK data in Table 2B are for all income brackets. As the own-price elasticity values for the large food groups indicate, in general, an increase in price leads to a decrease in demand. Braking food groups down in smaller units, however, does refine the view on this inter-dependency. Figure 3 indicates that bread has a price elasticity close to zero, due to its position as a staple in the diet with few, similarly priced substitutes available. Oils and fats, which hold a similar position in the diet, also have a price elasticity close to zero, whereas butter, which is perceived as a more luxurious product for which substitutes exist, has a price elasticity well below zero.

Of central interest to microbial food safety are meat and poultry. These food types have relatively high price and income elasticities and, as such, are likely to see a decrease in demand if food prices were to rise. This effect is likely to be strongest for expensive meats – in Great Britain this position is held by lamb, although this would vary across Europe. Such meats could be substituted by cheaper alternatives – e.g. poultry in Great Britain – and portion sizes may decrease. Such changes could have an impact on the burden of foodborne disease from these sources.

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Large price changes are predicted to have a significant effect on the consumption of many food types important to microbial safety, but what influences price? Figure 4A illustrates the main drivers of the supply price other than demand. Costs that are reflected in the sales price include transportation of goods and waste generated up to the point of sale, marketing and advertising, in addition to production and processing costs. These costs are strongly influenced by the economic environment, with oil and gas prices being key drivers, strongly affecting the cost of, for example, transportation fuel and ammonia-based fertiliser, for which natural gas is a feedstock. Competition for and pressure on land use are other long-term influences that feed into food prices. This is discussed in relation to demographic changes, climate change and biofuel feedstock production.

Consumption of major animal derived food groups important to microbial safety is illustrated in Figure 5A for the EU15 (the 15 countries that made up the European Union before the 2004 expansion). The graph shows the change in the gross human apparent consumption per capita, which adds up commercial production, the estimated own account production for self consumption, import and opening stocks and subtracts from this exports, usage input for processed food, feed, non-food usage, wastage and closing stocks. Gross human apparent consumption per capita of fish and seafood in 2001 (+8%) and meat in 2002 (+4%) were higher than in 1995, whereas consumption of milk declined (–6%) between 1995 and 2002. These data illustrate the fact that, when analysed at this level of food-type and geographical aggregation, consumption levels per capita change relatively slowly. The increased consumption of meat would have been influenced by the reduction in price relative to income; the agricultural output price of meat fell by 19.6% in real terms across the EU15 countries between 1996 and 2002 (Eurostat, 2008 a,b). Unfortunately, no aggregated EU data were available for fresh produce or eggs, which are food groups that have been more frequently associated with microbiological foodborne illnesses in recent years.

A breakdown of the gross human apparent meat consumption per capita by animal is shown in Figure 5B. It reveals that changes in poultry and pork consumption were responsible for the increase observed in meat consumption overall, whereas consumption of sheep and goats, and cattle declined. It is notable that the types of meat for which consumption increased also experienced the most significant prices falls in real terms (see Table 2C for changes between 1996 and 2002) and this would certainly have been a key factor in the observed shift in consumption patterns.

There have been recent and dramatic increases in agricultural commodity prices. For instance, during 2007 the FAO (Food and Agriculture Organisation of the United Nations) food price index increased by approximately 40% (FAO, 2008). The increase has been most obvious in dairy products, but is also evident in cereals and oils and fats. Probable drivers for these price changes include increased food demands due to greater population and affluence, high energy prices, competition for land-use from biofuel-feedstock production and poor production conditions in a number of important producer countries, such as droughts in Australia. However, prices of agricultural products are notoriously volatile, with sharp but brief peaks and persistent slumps. Since peaking mid 2008, agricultural commodity prices have fallen sharply, whilst food prices have declined but not as much (FAO, 2009; OECD/FAO, 2009).

In cases where food prices are higher due to increased demand, the difference between costs and commodity prices should increase and some of this difference could boost farmers' income. In contrast, where food prices are higher due to increased production costs, this could put downward pressure on farmers' income. The former case would represent an opportunity for agricultural investment, and indeed, investment could be encouraged in areas beneficial to microbial food safety.

The growing global trade in food means that food supply structures are complex and ever-evolving: rather than the traditional view of a linear supply chain, these structures now resemble a network akin to the Internet. Food components entering the supply network can be distributed and used in a wide range of products, which can make traceability in the case of a contamination incident a major issue, e.g. the occurrence of the illegal food colour Sudan I in a wide range of foods (Sudan I Review Panel, 2007).

The food supply network has seen numerous changes that enable the food supply network to benefit from economies of scale, with consolidation of, for example, suppliers of agricultural inputs (Tansey, 2008) and retailers (UK Prime Minister's Strategy Unit, 2008). Moreover, there has been greater co-ordination between companies, both those interfacing vertically in the supply network, and, in the agricultural input sector, horizontally via alliances between companies in similar fields (Tansey, 2008). Structural changes within this supply network have been occurring and this is likely to continue. If these changes and their implications for microbial food safety are not fully considered and managed, there is the potential for a significant impact on public health. Worldwide there are already examples of outbreaks of huge magnitude. In 1988, a Hepatitis A epidemic in China associated with the consumption of clams affected 292,000 people, killing nine of them (Rocourt et al., 2003). In a 1996 Japanese outbreak, at least 9,578 individuals (mainly schoolchildren) suffered from severe *E. coli* O157:H7 infections linked to white radish sprouts (Mead et al., 1999). In 2000, an outbreak from milk in Japan resulted in almost 6,000 illnesses; the contamination point was a production line valve that became contaminated (Adak et al., 2002).

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Effective management of food safety in an ever more complex global food business will require the use of new risk management tools that allow the management of risk at appropriate points in the food chain.

3.3. Social Drivers.

Price is not the only factor determining food consumption patterns, with choices also based on how the quality of food is perceived and valued. Convenience, health issues and sensory perception of food have been identified as three key drivers affecting consumer choice in Europe and the USA (Datamonitor, 2006). These drivers are illustrated in Figure 4B, alongside other influences including religious and cultural (e.g. vegetarianism; halal and kosher foods) and concerns regarding sustainable living and animal welfare (e.g. intensive production, organic, fair trade and carbon footprint). Changes in the public's perception to food quality are complex and difficult to predict. Furthermore, the difference in perception between countries is marked. Alongside gradual shifts in perception, punctuated change occurs as. illustrated by the sharp reduction in egg consumption in the United Kingdom in 1988, after a significant change in the perceived risk from *Salmonella* Enteritidis.

Perceptions of food are influenced by a wealth of information of varying quality. For instance, the United Kingdom public named the following organisations when asked who provided their information on food safety and food scares: Government Departments, supermarkets, local councils, food manufacturers, consumer groups and the media (FSA, 2007b). Where accurate and balanced information on food safety is available to the public, there is the possibility for self-control in the system relating to consumption of foods associated with a risk. For instance, to an extent, the public seek to minimise their exposure to food-based risk and access to information can aid this minimisation. An example of this is the reduction in foodborne disease in Los Angeles after the hygiene ratings of restaurants were displayed at the entrances of premises (Zhe Jin & Leslie, 2003). In this case, enforcement activities on accessibility of information impacted on consumption behaviour and the foodborne disease burden.

Convenience is currently a key factor in determining food choices. This trend is due in part to increased time pressure on people's lives, which has manifested itself in a reduction in food preparation time (Cheung et al., 2007). Other related trends include the increase in supermarkets' share of the grocery market and consumption of foods requiring less preparation time, e.g. ready meals (UK Prime Minister's Strategy Unit, 2008). This increase in supermarkets' share of the grocery market has not been confined to large stores. The creation in recent years of smaller high-street supermarket outlets with extended opening hours reflects the trend in Europe and the US of fewer large shopping trips, in favour of more 'immediate' grocery shopping (Datamonitor, 2008). Interestingly, the increase in the number of products available has reached the point where consumers would prefer less choice. This became evident in a recent consumer survey in Europe and the USA, where it was found that more consumers agreed than disagreed with the statement the there is now too much choice when making most purchase decisions (Datamonitor, 2008).

Taking the UK as an example, consumers spend a greater proportion of their food budget eating out than they have done in the past, although in the last 5 years, this trend has levelled out. This reflects the increase in disposable income available relative to food prices (UK Prime Minister's Strategy Unit, 2008). Although convenience is a strong driver, other preferences relating to consumer behaviour are exerting themselves, such as an increasing desire for home-cooking, and an associated aspiration to increase fresh ingredient usage (Datamonitor, 2006). It is noted, however, that these desires are not often realised due to time pressures. This has led to the recent development of products that facilitate 'meal assembly', i.e. the use of semi-prepared ingredients to create a meal. The use of meat products, including marinated and semi-cooked variants, has the potential to impact on foodborne disease if information on preparation, cooking and storage is not clearly conveyed to or followed by the consumer.

The trend in convenience has seen an increase in the ready meals market, which is still growing fast in established markets such as in Spain, Italy and other southern European countries. The largest and most developed market in ready meals is in the US where, overall, it is growing more slowly. However, an exception is the market for chilled ready meals. This is the fastest growing sector of the ready meals industry and is expected to grow at CAGR (compound annual growth rate) of 3.8% between 2004 and 2009 to reach US$9.0 billion (Eastwood, 2006). These trends in convenience foods can lead to the emergence of new microbial hazards. An example of this was the development of the chill supply chain in the UK throughout the 1970s and 1980s. This manufacturing and supply chain provided favourable conditions for the contamination and growth of *L. monocytogenes* in ready to eat foodstuffs. Although several other foodborne pathogens (e.g. *Yersinia enterocolitica*, psychrotrophic *Bacillus cereus* and non-proteolytic *Clostridium botulinum*) may be able to grow at refrigeration temperatures, the significance of *L. monocytogenes* as a foodborne pathogen in the UK was not fully recognised until there was a rapid increase in human cases of listeriosis in the late 1980s. Contamination of pate with *L. monocytogenes* has been suggested as a likely contributory cause of this increase since the subsequent decline in cases has been attributed to the issuing of government warnings on pate consumption to vulnerable groups and the withdrawal of the likely contamination source (McLauchlin et al., 1991). Testing of the chill supply-chain infrastructure and retail foods at the time revealed widespread contamination with *L. monocytogenes*, and this precipitated an extensive cleaning operation to address the problem (Malcolm Kane, personal communication). The above illustrates the need for understanding and communication throughout the industry of

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the implications for food safety of structural changes in supply-chain infrastructure or the introduction of novel food concepts. An example of the latter may be the so called 'Not-Ready-To-Eat' (Not-RTE) foods. Not-RTE foods in the US are considered 'raw' for the purposes of current regulatory focus regarding sanitary conditions and presence of pathogens, whereas Ready-To-Eat (RTE) products are identified as safe to consume without further lethality treatment. Heating of RTE products may be applied for palatability purposes but is not required to ensure product safety. The growing market for Not-RTE, providing particular convenience to consumers, has lead to food safety concerns since a number of outbreaks have occurred recently with Not-RTE products in the US. Mostly, these were due to the consumer not properly reheating or cooking products that require thorough cooking to ensure product safety. Frequently the products involved appear like they may be already cooked, for example pre-breaded raw poultry products, and often microwave re-heating is also an important factor (FSIS, 2006).

Other recent trends in consumer patterns include the rise of so-called ethical foods, including elements of organic production, fair trade, assurance of farming standards and animal welfare. Associated with these trends is a growing emphasis on local produce. The degree of uptake varies strongly between countries and in part is due to availability of products, and willingness to pay a premium for these goods, which in turn depends on perceived benefits and relative income levels.

Public bodies in many countries are actively engaged in promotion of a balanced, nutritious diet. The funding for these activities may grow in light of the obesity problem many countries are experiencing and the associated increase in healthcare costs. Such a trend has the ability to influence food choices relevant to microbial food safety. If protein sources high in saturated fats are discouraged in favour of alternatives, red meat consumption could decline in favour of poultry, fish and vegetarian options. Specific nutrition-related activities could also

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affect microbiological safety in particular ways, e.g. reducing salt levels in processed foods could shorten the shelf-life of certain products unless such foods are reformulated to ensure there are adequate preservation hurdles to prevent or minimise growth of microorganisms of concern.

Fresh produce consumption could also be encouraged as an alternative to processed foods. In the UK, the awareness of eating a minimum number of fruit and vegetable portions a day rose from 43% in 2000 to 71% in 2006 (FSA, 2007b), which has been accompanied by a 9% increase in the weight of fruit and vegetable purchases (excluding potatoes) between 2001/2 and 2005/6 (Expenditure and Food Survey, 2008). Although fresh fruit and vegetable are important to the health and well being of the consumer from a nutritional standpoint, in the last few years the number of reported outbreaks of food-borne disease associated with fresh produce has increased considerably (FAO/WHO, 2008). Outbreak attribution data in the US (CSPI, 2006) suggests that fresh produce is the leading cause of food borne disease in terms of number of case in the US, with salads accounting for about a quarter of this burden. From a global perspective, leafy green vegetables also currently represent the greatest concern in terms of microbiological hazards associated with fresh produce. Leafy greens are grown and exported in large volume, have been associated with multiple outbreaks with high numbers of illnesses in at least three regions of the world, and are grown and processed in diverse and complex ways, ranging from in-field packing to processed bagged product (FAO/WHO, 2008). With the possible exception of irradiation in the USA, there is currently no single, fully effective and validated kill step in the production of leafy greens. Though not fully effective, washing and chlorination are often used for leafy greens and can contribute to an ultimately validated kill step. Notably, for leafy greens, food safety often relies on prevention of contamination during growing and harvesting, which can be a relatively weak form of hazard control, especially in a raw agricultural setting, when used without additional control measures.

Marketing and advertising are likely to play a continued strong role in shaping food preferences. The nature of this role will be determined by how food brands and retailers wish to be portrayed - e.g. as having the public's health as their concern - and how advertising regulation and implementation develops with time. The increasing number of communication technologies available is likely to alter the methods used to influence consumer choice.

A large proportion of food choices can be described as 'inherited', whereby people purchase products and food types that they have historically bought. This practice may be strengthened in the future with the increase in on-line shopping, whereby the customer has the option to build up their current purchase using a previous shopping basket as the starting point.

Other shifts in food preferences that are more minor on a global scale or that are more specific to a country or a region are highly difficult to predict and are influenced by a wider range of factors than discussed in this paper. For this reason, this is an area of consumer behaviour where monitoring trends is likely to be more effective than prediction.

Global food demand is closely linked to global population, which is predicted to rise from 6.6 thousand million people in 2008 to between 7.4 and 7.8 thousand million in 2020 (United Nations World Populations Prospects, 2006). Thus, the world food demand is likely to grow substantially over this period, not only from this rise in population, but also from an increasing urban and affluent population in countries with emerging economies, as detailed by Schmidhuber (2003) and typified by China and India in recent years. These trends will continue to exert an upward pressure on food prices and could reduce the global availability of certain foods.

In contrast to the world population, Europe's population is predicted to be relatively stable, reducing from 730 million in 2008 to 720 million in 2020 (reference as in previous paragraph). Given that the EU is self-sufficient in many food types that may impact on foodborne disease (e.g. Table 2A), this creates a degree of security of food availability in the future and a moderating influence on food prices in Europe relative to global prices. As noted by the UK Prime Minister's Strategy Unit (2008), it is the food-importing developing countries that are likely to face the biggest challenges as a result of increasing world food prices.

Although the population of Europe is set to remain relatively constant, the age structure is estimated to alter significantly, for example, predictions show that in 2020, 30% of Germany's population will be 60 years old or above, compared with 25% in 2005 and 37% by 2050 (United Nations World Populations Prospects, 2006). The susceptibility to and severity of many foodborne diseases increases with age: e.g. the increase in listeriosis cases noted in several EU countries in recent years has been seen mostly in the elderly population (Denny and McLauchlin, 2008; Goulet et al., 2008), and the proportion of *Campylobacter* cases requiring hospitalisation has increased markedly in the patients over 75 years old (Gillespie et al., 2005). The reasons for the increased severity and susceptibility are not fully understood but are likely to include a lowered efficiency of the immune system and oxidative damage leading to ageing and increased vulnerability to diseases related to the occurrence of cellular damage for instance due to the action of reactive oxygen species. In addition, other physical and mental deterioration, food choices and behaviours may play a role. Although physical deterioration is not solely determined by age, it is likely that the increase in the population of older people will put upwards pressure on the foodborne disease burden. It should also be noted that the food choices of tomorrow's older people will not necessarily be the same as today's older generation.

Migration into and away from Europe will continue to be affected by EU expansion, relative income, perceived quality of life, immigration rules and the extent of conflict zones around the world. The future trajectory of these drivers is hard to predict, but they are likely to influence the food preferences within Europe. If immigration causes a major shift in food consumption and preparation techniques, it is possible for this to alter the burden of foodborne disease.

3.4. Technological Drivers.

For many decades, the food sector investment level has been relatively low as compared to that in the industrial sectors. In recent years, return on investment of broad benefits derived from agricultural research has provided tangible measurement of the substantial value of research and development (R&D) in agriculture (Onwulata et al., 2008). Despite this, a decade or so of focus on consolidation and efficiency has left investments in R&D in the food industry extremely low compared to other industry sectors. For example, investment in R&D as a percentage of value of production in the food sector for Europe was 0.32% in 2003 and for the United States was 0.39% in 2002, compared to the chemical, rubber, plastics and fuel products in OECD countries of 2.72% in 2001. The lack of investment in innovation has also seen the food industry become one of the least profitable industry sectors. Clearly, an increase in investment will be needed if the food industry is to overcome many challenges of globalization and realize the growth opportunities of meeting important consumer drivers such as health, convenience, pleasure and environmental awareness. Indeed, new product development was selected as the most important investment area for building competitive advantage by a global panel of food and drink executives surveyed by Business Insights in December 2006 (Meziane, 2007). Recent advances in food science and technology, such as novel preservation technologies, offer exciting new possibilities for innovation to meet the above mentioned consumer drivers. Despite the opportunities, care should be taken not to introduce new food safety hazards through deploying new technologies. For example, most novel preservation technologies such as non-thermal treatments cannot currently be relied upon to inactivate bacterial spores which means that they

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must be combined with an additional preservation hurdle such as refrigeration or acid formulation to prevent spore outgrowth (Food Safety Magazine Panel, 2007).

In the last few years there has been growing research and commercial interest especially in Europe and the United State in a number of specific non-thermal or cold pasteurization techniques. Interest in, for instance, high pressure processing (HPP), UV treatment, pulsed electric field treatments and ionizing irradiation has been fuelled by a continuing consumer desire for foods that appear fresh, but are also convenient and safe. A decontamination step that does not significantly alter the organoleptic or nutritional qualities of the food would have obvious advantages. Cold pasteurization technologies offer the promise of foods that have a freshness of flavour, colour, texture and nutritional value closer to non-heated products while, at the same time, exhibiting enhanced microbiological safety.

Of the preservation technologies that are novel in terms of practical application, HPP has probably advanced further than any of the other alternative physical food processing technologies. One of the major processing advantages is that pressure is transmitted uniformly and instantaneously throughout the food product, therefore there is no gradient of effectiveness from outside to inside as there is with thermal processing. Due largely to the advancement of the engineering of the equipment, HPP has become an economically viable process in the last decade or so. Today, high pressure ‘pasteurization’ has become a commercial reality with over 120 commercial operations worldwide. Several fruit- and vegetable-based refrigerated food products are currently on the international market, including a range of juices and fruit smoothies, jams, apple sauce-fruit blends, guacamole and other avocado products, tomato-based salsas and fajita meal kits containing acidified sliced capsicum and onions and heat and serve beef or chicken slices (acidified and precooked). Additionally, ready-to-eat meat products and seafood, including oysters, are on the market in the U.S. and Europe (Smelt, 1998; Stewart and Cole 2001). The use of HPP for the pasteurization of sliced meats is an excellent example of how the technology can be used to both enhance food safety and meet consumer trends. The technology provides a robust in pack pasteurization with respect to *L. moncytogenes* with relatively little impact on product quality. It also allows manufacturers to eliminate preservatives from the formula and to be able to make an 'all natural' claim in the US. Another potential for the technology is in the inactivation of foodborne viruses in shellfish (Grove et al., 2006). HPP uses pressures of approximately 300 to 700 MPa for a few seconds or minutes to destroy vegetative microorganisms, and can be thought of as a "cold pasteurization" process. Typically, 10 min exposure to HPP in the range of 250-300 MPa or 30-60 sec exposure to HHP in the range of 545-600 MPa exerts a pasteurization effect (Hoover, 1997). Notably, microorganisms are quite variable with regard to their sensitivity to HPP. Results of experiments conducted by Shigehisa et al. (1991) suggest that the order of sensitivity to HPP is Gram-negative bacteria > yeasts > Gram-positive bacteria > bacterial spores. Bacterial spores are actually highly resistant to HPP, even to pressures of up to 1000 MPa (Timson and Short 1965; Sale et al., 1970; Cheftel, 1992), and hence a combined treatment of parameters such as pressure, mild heat and low pH is typically required for inactivation and control of outgrowth.

Ultraviolet (UV) treatment is another non-thermal technology that holds considerable promise in food processing as an alternative to traditional thermal processing. Its applications include pasteurization of juices, post lethality treatment for meats, treatment of food contact surfaces and extending the shelf-life of fresh produce. This technology is a particularly attractive cold pasteurisation option for certain high throughput liquids such as beverages. Studies such as that of Koutchma et al. (2006) have allowed the technology to be validated as an alternative to heat pasteurisation for juices requiring a 5 log kill of *Salmonella* spp. in the USA.

A technology showing promise for food quality but one that is yet to be commercialised is Pulsed Electric Field (PEF) treatment. PEF technology utilizes high strength electric fields, typically up to 50 kVolts/cm, in extremely short time pulses ranging from a few microseconds to milliseconds. Other parameters of PEF processing include the number of pulses given, typically less than 100, as well as the pulse shape, including exponential decay, square, wave or oscillatory pulses. The pulses may also be monopolar or bipolar. With PEF processing, food is treated for a short period of time and the energy lost due to heating of food is minimal, therefore the efficiency of the process is high (Qin et al., 1996).

Perhaps one of the oldest and most studied non-thermal technology is food irradiation, which is approved as a food processing method in 43 countries including the U.S., the UK, Belgium, France and the Netherlands. There is an extensive amount of information available in the literature about food irradiation, including reviews by Radomyski *et al*. (1994), Monk et al. (1995), Farkas (1998) and Barbosa-Canovas et al. (1998). There are currently two main methods of producing the ionizing radiation sources for food applications: gamma radiation and electron beam radiation. Gamma radiation is the traditional radiation method and the radioisotope used in most commercial facilities is cobalt 60. The mechanisms for microbial inactivation by irradiation are well known. Irradiation irreversibly damages microbial DNA leading to the inability of the organism to reproduce. There are over 45 years of extensive studies documented in the scientific and technical literature detailing chemical and microbial effects of irradiation of food and reporting decimal reduction times (D_{10}-values) for most foodborne pathogens and many food spoilage organisms. A data analysis of D_{10}-values achieved with irradiation for bacteria and spores has been undertaken and provides approximate estimates of this parameter that can be useful in designing and evaluating irradiation processes under various conditions (van Gerwen et al., 1999). The World Health Organisation has approved irradiation dosages for foods of up to 10 kilograys (kGy) as “unconditionally safe for human consumption”. Despite this, the key impediment for the commercialization of food irradiation is consumer acceptance. Technically, food irradiation provides a highly effective mitigation measure for foodborne microorganisms and its commercialization would be expected to have a profound effect on the incidence of foodborne diseases globally. However, the consumer attitude to food irradiation is a complex issue in which acceptance of the technology may ultimately be weighed against the risks of illnesses due to foods. For example, acceptance of irradiated foods increased significantly when the consumer was provided with information on the advantages of the technology in terms of enhanced product safety and wholesomeness of the product (Bruhn, 1998). At the moment still, it is very difficult to predict whether consumer acceptance would ever allow its commercial use in mainstream food industry.

Innovations in our ability to assess and quantify harmfull micro-organisms underly a quite different area of technological drivers. The attribution of an adverse public health effect such as illness to a particular pathogen requires detection of the particular pathogen, which might be at the health care provider or local health department level. Investigation usually includes case definition, symptoms and severity of the disease and an investigation of how illness occurs along with sources of exposure. Surveillance helps to understand the trends in incidence of the disease and role of specific foods. Surveillance is also important in the consideration of potential control strategies by identifying which steps in the food chain could offer the most effective control measures (Tompkin, 2007). Surveillance is crucial to monitor the impact of any resulting control measures or public health policy (ICMSF, 2006). Advances in subtyping technologies (e.g., PFGE) and information technologies permit human and food isolates to be accurately matched, resulting in the identification of foodborne outbreaks that until recently would have gone undetected. In particular, the fields of 'omics' data generation, bioinformatics driven data analysis and systems biology offer great opportunities for specific data generation to better understand the resilience of microbial pathogens in foods and assess preservation targets. In combination with new developments of detection systems for food-borne pathogens as well as the development of new predictive models these fields hold the promise for significantly furthering our understanding of the biological systems at hand both at the level of the microorganism but likely also at the level of the host as discussed elsewhere (Havelaar et al, accepted; Brul et al., 2006, 2008).

Although not a processing technology, developments in the science of food safety management and risk management for the purposes of this paper could also be considered a technology capable of having a profound impact on our ability to reduce the burden of foodborne diseases (ICMSF, 2002; Gorris et al., 2007). Control measures for particular microbial hazards are developed based on an understanding of both the food vehicle as well as the parts of the food chain that would be most effective in applying the control measures to. For instance, in the case of *L. monocytogenes* contamination of RTE meat products in the US (Tompkin, 2007) control measures for *L. monocytogenes* included: preventing recontamination after the kill step by detecting and eliminating environmental harborage sites, improving equipment design to facilitate cleaning, the addition of inhibitors to products (e.g., lactate, diacetate) and pasteurizing packaged product (i.e. steam, hot water, ultra high pressure). Alternative control measures available for fruit juices achieving the 5 log kill of *Salmonella* and other enteric pathogens required in the US may well have contributed to a significant reduction of fruit juice associated outbreaks since the requirement was introduced in 2002 (Scott and Huffman, 2007, Vojdani et al., 2008). Increasingly, the development of control measures is based on public health risk and is outcome based, which leaves flexibility on how different operations chooses to apply the required degree of control (ICMSF, 2002). In addition, the complexity of today’s food safety issues frequently

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means that the problem cannot be solved with one single control measure but instead requires a combination of measures to effectively reduce risk.

3.5. Regulatory and Trade Drivers

An increase in the number of incidents related to food safety in recent years has led to nothing less than a paradigm shift in the way that food safety is managed. Regulatory efforts internationally have been focused on the use of risk assessment tools to drive food safety policy and standards away from prescriptive to outcome based control measures. The safety of foods in international trade is a matter often discussed by the World Trade Organisation (WTO, 1994) which recognizes that governments have the right to reject imported foods when the health of the population is endangered. The criteria used to determine whether a food can be considered safe should be clearly conveyed to the exporting country and should be scientifically justifiable. In order to achieve this, the term 'appropriate level of protection' has been used, which is defined as "the level of protection deemed appropriate by the member country establishing a sanitary or phytosanitary measure to protect human, animal or plant life or health within its territory". Traditionally, and specifically for contaminants and toxins deemed unavoidable in foods, this has been defined in terms of having a chemical or microbial risk "as low as reasonably achievable" (ALARA). This definition has caused great difficulties for a number of reasons. Although trade is becoming increasingly global, the technological capabilities of different countries, and even different companies within the same country, remain very different. Also, the idea of what is considered "reasonable" differs from country to country and a society's sense of acceptable risk is in part culturally defined.

Developments in the areas of predictive modelling and risk assessment now offer the potential to link characteristics of the food chain and the microbial hazards to the exposure and further to the likely number of cases of illness in the population and are driving new risk management approaches based on concepts such as of Food Safety Objectives and Performance Objectives (CAC, 2007). The approach enables the food industry to meet a specific objective through the application of the principles of Good Hygienic Practice (GHP) and Hazard Analysis Critical Control Point (HACCP), which are established on the basis of performance criteria, process- and/or product-criteria and other control measures that are appropriate for the particular food, the food operation and the food-supply chain involved. It provides a scientific basis that allows industry to select and implement control measures specific to its operations. This approach should also enable regulators to, where necessary, better select “safe harbour” control measures for industry that are based on process-based (prescriptive) standards and are assumed to satisfy performance-based (outcome) standards.

The new risk management approaches that are outcome based offer flexibility of operation, which can be very important when considering the most effective control measures in a particular region or operation. However, perhaps the most critical aspect of these new developments in terms of the global foodborne disease burden is whether such new approaches allow for food safety control measures and regulations to be developed and implemented more rapidly, for instance by the development of novel analytical tools for rapid near real-time detection.. Many of the food safety issues that societies face today are more complex in nature, frequently requiring through-chain approaches and relying on more than one control measure to effectively manage risk. It is envisaged by regulators around the world that the new risk management guidelines will offer a framework that will facilitate communication between stakeholders on the most effective food safety management options thereby speeding the development of effective risk management. A good example of a recent CODEX code that benefited from these developments is the Code of Hygienic Practice for Powdered Formulae for

Infants and Young Children (CAC, 2008). This code addresses the emerging public health threat of *Cronobacter* spp. (previously referred to as *Enterobacter sakazakii*), which was brought to the attention of Codex Alimentarius in 2002/2003 who then asked FAO and WHO (World Health Organisation) to convene an expert consultation on the topic in February 2004 (FAO/WHO, 2004). The consultation used risk management principles to look at a range of control strategies during both manufacture and subsequent use of powdered infant formulae that could be implemented to reduce risk. Importantly, the approach facilitated the formulation of urgent advice to different stakeholders, including caregivers of infants, consumers and industry and ultimately led to a timely update of the code in 2008 (CAC, 2008).

Alongside the proportion of different food types being consumed, the origin and production method are also important to microbial safety. Where food comes from is determined by another set of inter-connected factors which include development of trade links, levels of import tariffs, geographic proximity of exporter and importer countries, transport costs, exchange rates, and relative costs for production, manufacturing and storage costs. Trade links, which are closely connected to import tariff levels, develop over a relatively long time-scale. In contrast, exchange rates can fluctuate on a much shorter time scale (hours or days), influencing choice of supplier, although variability is reduced by the practice of agreeing fixed exchange rates for the duration of contracts. The importance of geographical proximity is determined by the type of food (e.g. stability, durability), transportation and storage costs, and social acceptability of transportation over longer distanced versus local production. Recent negotiations relating to global trade are, in general, reducing the level of import tariffs and liberalising global trade. One example is development of the Economic Partnership Agreements between the EU and members of the Africa, Caribbean and Pacific group. These would allow specified countries quota-free and duty-free access to the EU markets. Although this has the potential to radically increase the amount of food imported into the EU, in practice it is likely that change will be gradual as many of the relevant exporter countries do not have the capacity to fill their current quotas (Stevens et al., 2008). Furthermore, imports in food types important from the perspective of microbial safety (i.e. foods of animal origin) are relatively small compared with apparent consumption in the EU whereas the trade in fresh produce in the region is significant.

Although most food groups that impact on microbial safety are likely to see only a gradual shift in supplier countries, foodborne disease may still be substantially affected. Microbial contamination incidents and outbreaks relating to food can be caused by a small proportion of food consumed, and thus foodborne disease patterns can be affected disproportionately to the change in trade. Therefore identifying problems with particular food groups associated with potential supplier nations is important in identifying future risks.

Another driver that could lead to further food imports into the EU is reform of the Common Agricultural Policy (CAP). Recent changes have seen subsidy decoupled from production, with the resulting reduction in food stocks held. Further reform of the CAP is in the pipeline, and, although the outcome is uncertain, there is the potential of further reduction in CAP subsidy levels, which could put financial pressure on EU producers.

3.6. Environmental Drivers.

The predicted doubling in the global demand for food by 2050 will increase the need to use more land for agriculture. Of all the potentially arable land, currently only around 12% is not forested or subject to erosion or desertification. One way to meet the future demand for food would be double the area of farm production, but this would have catastrophic effects on the environment through destruction of forests and loss of wildlife habitat, biodiversity and carbon sequestration capacity. Options such as making non-arable land arable or rework eroded land to arable may not be readily feasible.The only environmentally sustainable alternative is therefore to double productivity on the fertile, non-erodible soils already in crop production. The same forces will also see the demand for products from forests increase and at the same time biofuels production is claiming more and more land (Global Environment Facility, 2002).

Importantly, producing food is extremely costly in terms of water use. As examples, the following water demands have been estimated (Ron Sandland, CSIRO, Personal Communication) for the production of one slice of white bread, 28 L; one bottle of wine, 360 L; one potato, 500 L, one 225g steak, 4660 L. Overall, farmers use an estimated 70% of the fresh water used in the world. In order to meet the future demands for food the world's farmers will need to more than double production using less water than today. This will inevitably put more pressure on the use of re-claimed water, which will have an impact on food safety.

The world's arable land and fresh water are not distributed around the world in the same proportions, as is population. With predicted population growth, urbanization and broad-based economic development the food consumption of many less developed countries will outstrip their production capacity and it is likely that they will become larger net importers.

Meteorological effects that could impact on food production include increased air temperatures, and a shift in rainfall patterns including a general increase in extreme weather events, e.g. storms causing crop damage and flooding. Furthermore, drought-prone areas are likely to increase in extent, leading to loss of fertile land, southern Europe being one such example. In contrast, increased water availability and temperature in high-latitude areas could lead to no loss of, or even an increase in, cereal production. However, some of these benefits could be offset by crop damage from waterlogged soil and storms, pests and diseases. The impact on primary production will depend on the how adaptations to the new environment in agriculture are managed. Aside from agriculture, increased sea temperatures are likely to put further strain on aquaculture (International Panel on Climate Change, 2007).

Alongside these direct effects, significant indirect effects in response to climate changes could also occur. For example, the development of taxation and trading schemes related to the release of greenhouse gases have the potential to transform not only agricultural practices, but also have a huge impact on consumption of key food groups. Currently the different stages of food production, manufacturing and delivery experience different levels of emission levies – for example, in the UK methane emissions direct from cattle or nitrous oxide releases from fertiliser use are not subject to a levy, in contrast to fuel used by tractors to work the land. If the full economic cost to society from all parts of the production and delivery chain were included in such levies, the price of certain meats would rise relative to many other foods, thus substantially reducing their consumption, with a potential reduction of the impact on foodborne disease. Whether such changes to levy schemes occur is a large uncertainty in the future.

4. Discussion.

The coming decade is likely to see more challenges, and as a consequence changes, in the food system than has been experienced in the recent past. By understanding the system surrounding food consumption and trade, we can gain an insight into the associated impacts on microbial food safety. This provides a useful first step for planning, development of strategies, and prioritisation of actions.

Through a system-based approach, this paper explored plausible global and regional trends in future food consumption and its consequences for the burden of disease as related to food with emphasis on the European Union context. The key drivers and associated uncertainties include the following:

1. Food prices. These are likely to remain at elevated levels and future food availability is likely to become an important issue globally, though possibly less so in the EU. High oil, gas and energy prices, increased biofuel feedstock production, climate change, changing diets and increased world food demand all contribute to this trend. Pressures on food prices and food availability could lead to a reduction of consumption of expensive foods and foods that are land and resource intensive to produce (e.g. meat, especially beef). This then could cause an increase in consumption of foods that experience a lower level of price inflation. The latter could be a consequence also of the recent global economic downturn, with the concomitant loss of affluence in many parts of the world. The exact manifestation of any dietary shift(s) could have a significant impact on the magnitude and nature of the foodborne disease burden.
2. Global food trade. This may be impacted in a number of different directions. Taking EU policy as an example EU policy, on the one hand, trade agreements and reform of the EU Common Agricultural Policy would allow more countries access to EU markets. However, this could be countered by increased transport costs and the productivity of most other regions being reduced, relative to the EU, due to climate change. However, for foods imported into the EU from new trade-partner countries, it is important to consider foodborne-disease problems arising in the exporting country or region as, depending on the foodstuff and the nature of the hazard, they could impact on microbial food safety in the EU. It is recognised that there are several key uncertainties associated with global trade that would impact on foodborne disease via food consumption and behaviour. These include the reform of the Common Agricultural Policy, development of trade links and structural changes in the food supply network.
3. Climate change. The threat of climate change could lead to taxation or other levy systems being extended to all parts of food production. If such mechanisms were implemented, this

would put further pressure on prices and availability of food types and production methods associated with high levels of greenhouse gas emissions. This could create a shift away from meats (again, beef being particularly affected) and reduced use of synthetic nitrogen-based fertiliser. Key uncertainties here would include: the extent and impact of climate change and the degree to which different sectors of agriculture and food manufacturing adapt, and implementation of policies relating to greenhouse gas emissions at both the national and international level;

4. Demographics. An anticipated doubling of the global demand for food and international trade in food in the next few decades is considered as the most significant factor that will drive an increase in food-borne disease with a high degree of certainty. It is highly likely that the population of Europe will possess a higher proportion of older people in the future. This could put upwards pressure on the number and particularly the severity of foodborne disease cases. Furthermore, migration may change food consumption and preparation behaviour, thus altering the patterns of foodborne disease. Key uncertainties regarding the actual magnitude of this driver are linked to the actual extent that underlying drivers shape up, including migration into and out of Europe, evolution of consumer preferences and doubling of global demand for food.

Overall, increased consumption of certain food commodities known to be associated with foodborne microbial hazards will increase foodborne illness with a reasonably high degree of certainty. Examples here would include meat and poultry, driven by an increased ability to pay for high protein foods and fresh produce, driven by a trend towards health. Another factor that could increase burden of foodborne diseases, but with less certainty, is the increase in refrigerated foods and extended shelf-life foods driven by a trend towards the desire for convenient foods. The use of effective regulatory measures is considered a factor in our ability to reduce the food borne disease burden with a reasonably high degree of certainty given past experience. Other factors important to the ability to reduce the burden of foodbone diseases are the development and use of new food safety technologies and detection methods. The most important factor in reducing food-borne disease is likely our ability to first detect and investigate a food safety issue and then to develop effective control measures.

The certainty with which measures can be developed and effectively used to control new food safety issues in an ever more complex and changing global food supply is ultimately investment driven. Investment is required to develop the critical resources and infrastructure to develop effective global surveillance of foodborne diseases as well as to fund research on microbial hazards and their control. International developments in risk assessment and risk management techniques offer the potential to shorten the time taken to develop effective and practical control measures through their ability to handle complex food safety issues in food chains. However, their wide spread implementation will require the effective communication and alignment with existing risk management tools such as HACCP and this will again require investment. Although the present study is rudimentary and qualitative in nature, it illustrates that economical returns on investments are possible through food safety research and improvements in infrastructure. The use of complex modelling techniques could be useful in the development of a more quantitative cost-benefit study on food safety investment as well as providing valuable insight into the most effective areas to target investment in order to maximize the return to public health as well facilitating trade.

The trends signalled underscore the importance of having reliable surveillance data and systems regionally or even globally, as these could help to monitor new threats and to respond quickly, but also would assist tracking the success of newly introduced control measures. Considering the global context, a notable initiative that the WHO has established is the Foodborne Disease Burden Epidemiology Reference Group (WHO, 2008) which has been set-up to estimate the global burden of foodborne diseases. Given the growing reliance on food imports from both developed and less developed countries, it is a challenge for national governments to protect their consumers while facilitating fair trade. Conceivably, a country cannot solely rely on its own food safety management systems but would best share best practices and experiences in food safety management with its trading partners. In this regard, international standard setting bodies such as Codex Alimentarius might play a helpful role by the development of equivalent food standards aimed at reducing the burden of global diseases and facilitating international trade in food.

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Legends of Tables

Table 1. Estimated proportion of indigenous foodborne disease, by food group and type for England and Wales, 1996-2000 (source: Adak et al., 2005).

Table 2. Summary of economic indicators for several food groups. A. self-sufficiency of meats in 2002 for the EU15 (Source: Eurostat accessed, 2008a); B. price elasticitities by food group in the UK for all income brackets. (Tiffin, Arnoult and Irz, 2007); C. price change of meat by type (1996-2002, EU15), adjusted for inflation (Source Eurostat, 2008a).

Table 3. Population density data (multiple of million inhabitants) for several countries with indication of population fraction with income levels below 1\$/day and < 2\$/day (source: Source: World Bank, 2005).

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Legends of Figures

Figure 1. Selection of driving factors in different categories that influence consumption of a single food type.

Figure 2. Visual representation of the key factors likely to impact on foodborne disease. Whether factors are likely to increase or decrease the global burden of foodborne disease is plotted against the certainty of their impact.

Figure 3. Price elasticities in food in Great Britain for mid-income bracket showing the median (O) with error bars representing one standard error of the mean (Chesher and Lechene, 2002).

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Figure 4. A (Left panel): factors other than demand affecting the food supply price; B (right panel): influences on demand of consumption of a single food other than price and income.

Figure 5. A (top panel): gross human apparent consumption (mass) per head of selected major food groups in the EU 1991-2003; 4 B (bottom panel): gross human apparent consumption per head of population in the EU of various types of meat (1995 to 2002), indexed to 1995 level. From Eurostat: agriculture and fisheries statistics (Eurostat, 2008).

Figure 1. (Quested et al.)

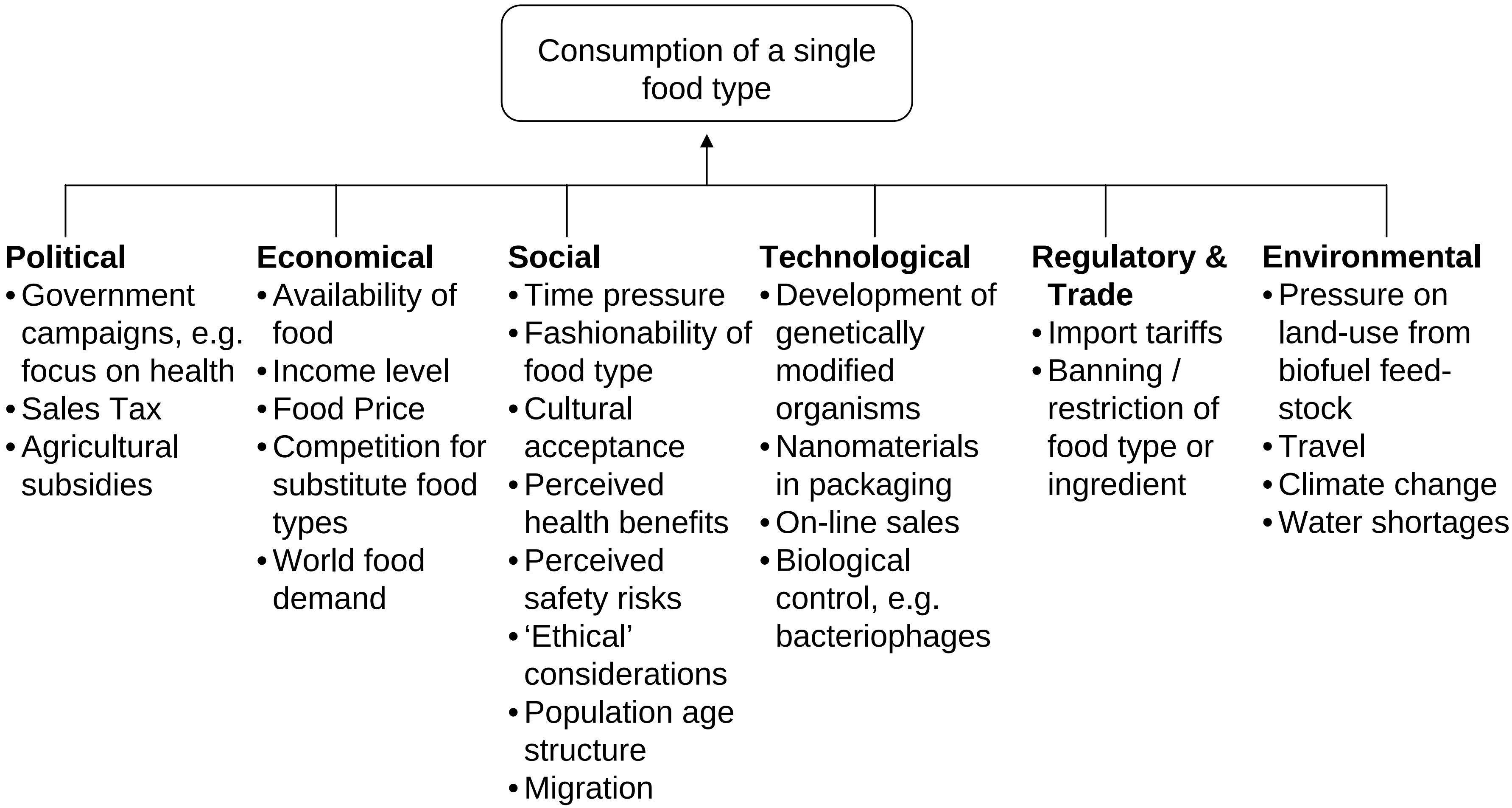
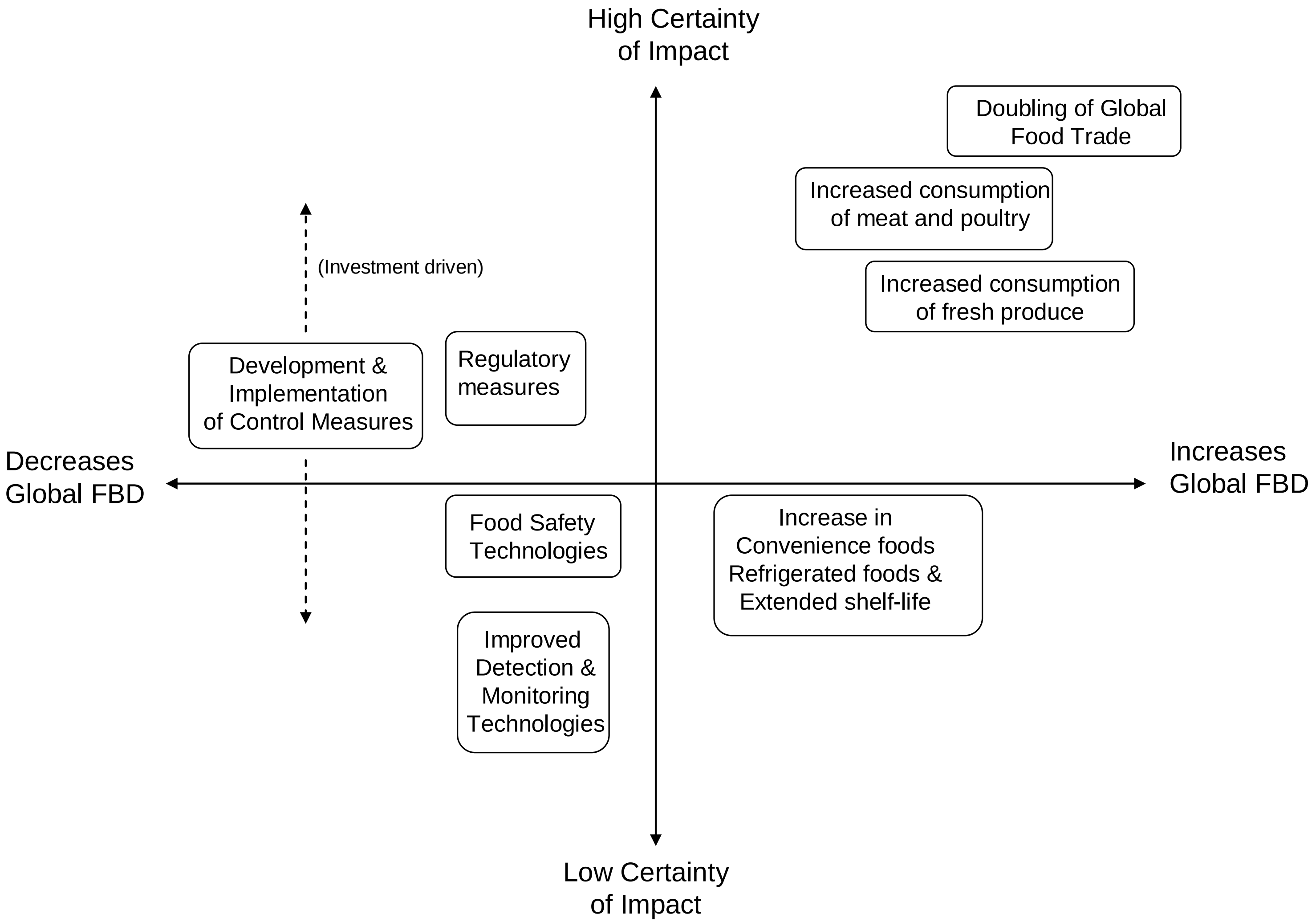


Figure 2. (Quested et al.)



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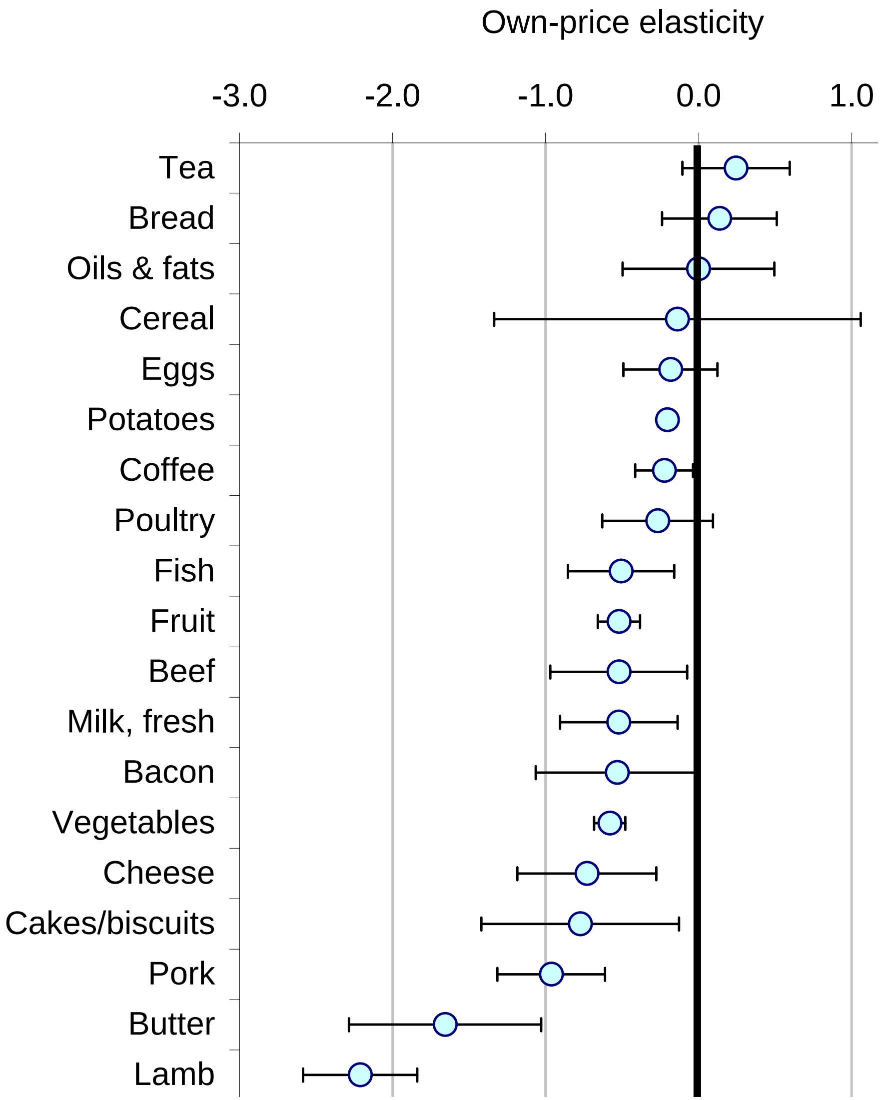


Figure 4A (left panel) and 4B (right panel) (Quested et al.)

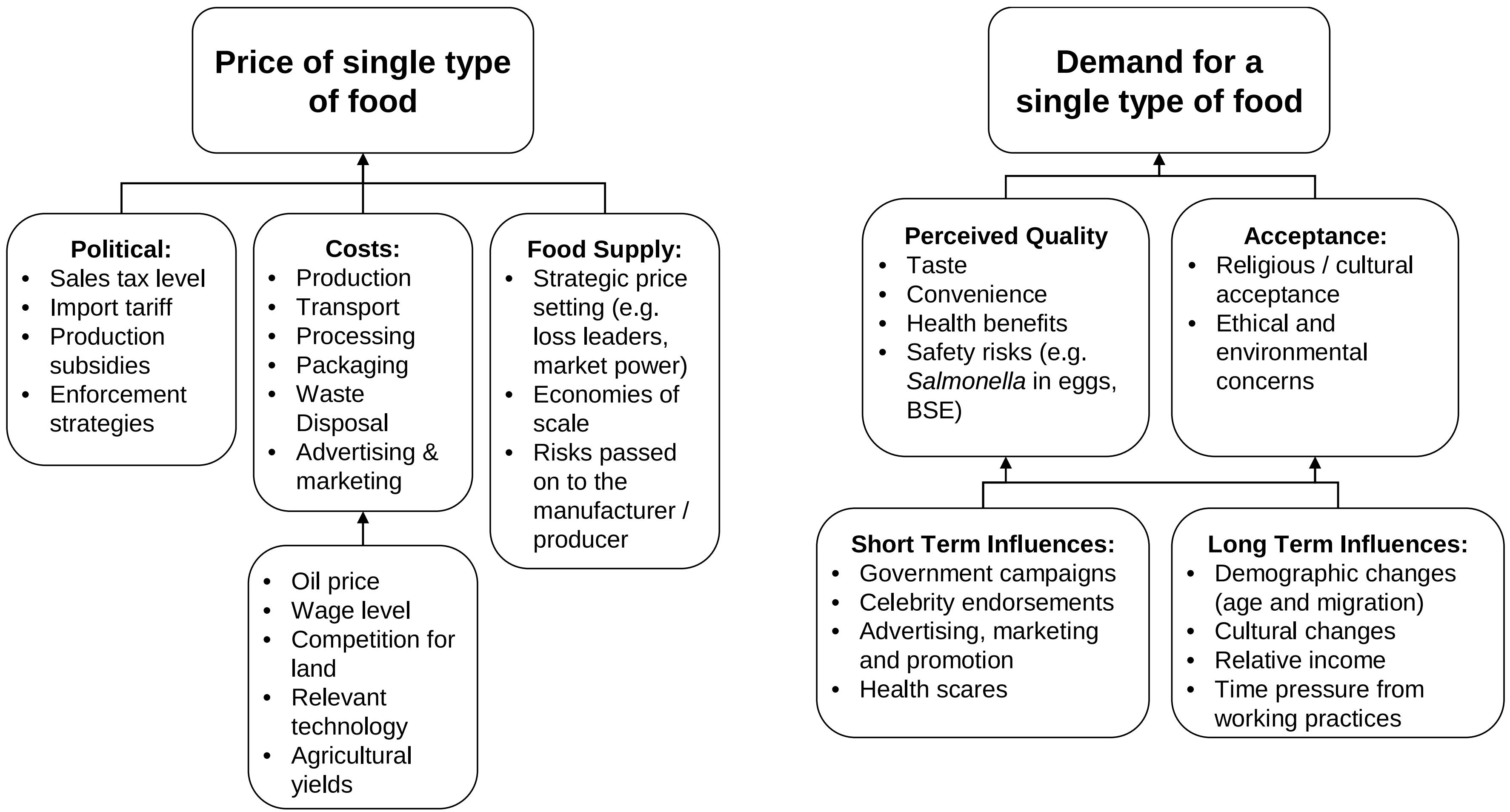
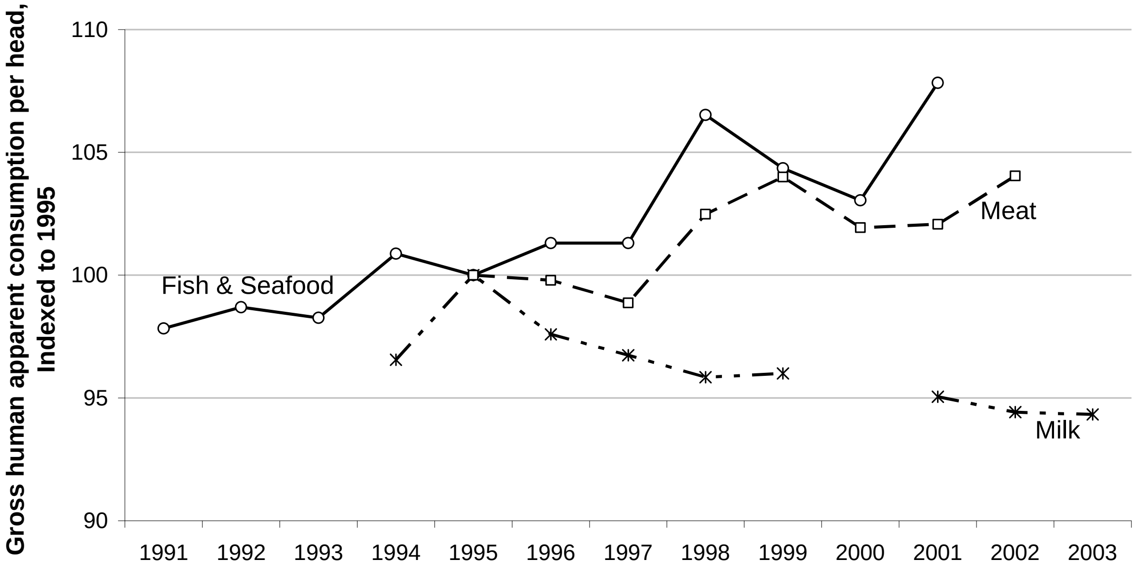


Figure 5A (top panel) and 5B (bottom panel) (Quested et al.)



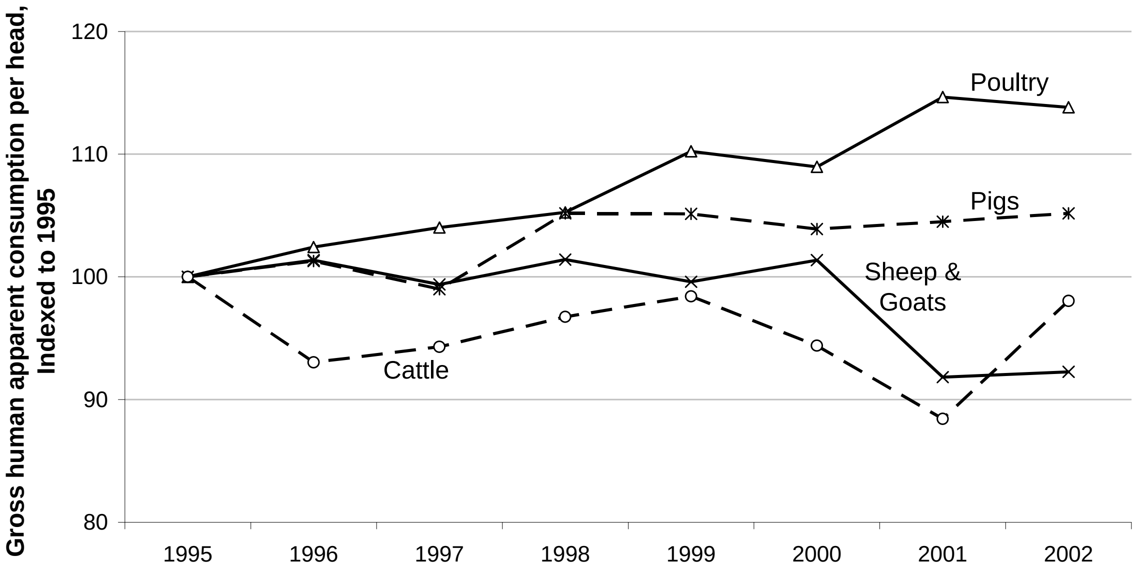


Table 1. Estimated proportion of indigenous foodborne disease, by food group and type for England and Wales, 1996-2000 (source: Adak et al., 2005).

Food Group / Type	Cases (%)	Deaths (%)
Poultry	29	28
Chicken	*23*	*21*
Turkey	*5*	*7*
Mixed / unspecified	*1*	*1*
Eggs	6	7
Red Meat	17	24
Beef	*7*	*10*
Pork	*3*	*4*
Bacon / Ham	*1*	*1*
Lamb	*3*	*4*
Mixed / unspecified	*4*	*5*
Seafood	7	4
Fish	*1*	*2*
Shellfish	*4*	*2*
Mixed / unspecified	*1*	*1*
Milk	6	5
Other dairy products	0	0
Vegetables / fruit	3	2
Salad vegetables	*2*	*2*
Cooked vegetables	*0*	*0*
Fruit	*0*	*0*
Rice	2	1
Complex foods	26	26
Infected food handler	4	2

Table 2. Summary of economic indicators for several food groups. A. self-sufficiency of meats in 2002 for the EU15 (Source: Eurostat accessed, 2008a); B. price elasticitities by food group in the UK for all income brackets. (Tiffin, Arnoult and Irz, 2007); C. price change of meat by type (1996-2002, EU15), adjusted for inflation (Source Eurostat, 2008a).

	Parameter	**Food group / type**	**Value**
A	**Self-sufficiency (%)**	Meat - total	106
		Cattle	101
		Pigs	109
		Sheep and goats	81
		Poultry	107
B	**Own-price elasticity**	Meat, fish & alternatives	–0.88
		Cereals & potatoes	–0.66
		Fruit & vegetables	–0.66
		Fats & sugar	–0.52
		Milk & dairy	–0.40
C	**Change between 1996 and 2002 (%)**	Meat total	–19.6
		Cattle	–12.1
		Pigs	–26.5
		Sheep and goats	–9.7
		Poultry	–19.6

Table 3. Population density data (multiple of million inhabitants) for several countries with indication of population fraction with income levels below 1$/day and < 2$/day (source: Source: World Bank, 2005).

Country	**Population (x 10^6)**	**% < 1$/day**	**% <2 $/day**
China	1299	16.6	46.7
India	1065	34.7	79.9
Indonesia	239	7.5	52.4
Brazil	184	8.2	22.4
Pakistan	159	13.4	65.6
Russia	144	6.1	23.8
Bangladesh	141	36.0	82.8
Nigeria	126	70.2	90.8
Mexico	105	9.9	26.3