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

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20 Technology, trade and consumption trends.

21

22 *Keywords:*

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24 **Abstract**

25
26 Current and potential future trends in technology, consumption and trade of food that may
27 impact on food-borne disease are analysed and the key driving factors identified focusing on the
28 European Union and, to a lesser extent, accounting for the United States and global issues.
29 Understanding of factors is developed using system-based methods and their impact is discussed
30 in relation to current events and predictions of future trends. These factors come from a wide
31 range of spheres relevant to food and include political, economic, social, technological,
32 regulatory and environmental drivers. The degree of certainty in assessing the impact of
33 important driving factors is considered in relation to food-borne disease. The most important
34 factors driving an increase in the burden of food-borne disease in the next few decades were
35 found to be the anticipated doubling of the global demand for food and of the international trade
36 in food next to a significantly increased consumption of certain high-value food commodities
37 such as meat and poultry and fresh produce. A less important factor potentially increasing the
38 food-borne disease burden would be the increased demand for convenience foods. Factors that
39 may contribute to a reduction in the food-borne disease burden were identified as the ability of
40 governments around the world to take effective regulatory measures as well as the development
41 and use of new food safety technologies and detection methods. The most important factor in
42 reducing the burden of food-borne disease was identified as our ability to first detect and
43 investigate a food safety issue and then to develop effective control measures. Given the global
44 scale of impact on food safety that current and potentially future trends have, either by potentially
45 increasing or decreasing the food-borne disease burden, it is concluded that a key role is fulfilled
46 by intergovernmental organisations and by international standard setting bodies in coordinating
47 the establishment and rolling-out of effective measures that, on balance, help ensure long-term
48 consumer protection and fair international trade.

49 1. Introduction.

50
51 Though there is little quantitative, concrete evidence that the globalization of food production and
52 marketing has an impact on food safety as it is experienced day-by-day by consumers around the
53 globe, it is very likely that globalization of the food supply as well as other global trends put
54 pressure on the burden of food-borne illnesses in many parts of the world. Technological and
55 infra-structural changes in food supply chains and the ever expanding trade worldwide have
56 changed the pace and distances at which an enormous variety of foods are brought to the
57 consumer's home. While consumers benefit by the product variety available to them, the
58 complexity of the global food supply requires more international collaboration and harmonization
59 of management efforts in order for existing and emerging risks to consumers to be dealt with
60 adequately. It is evident that changes in food production, processing, distribution and
61 consumption at a global scale have impacts well beyond the direct health and wellbeing of
62 consumers. They have major economical, social and environmental impacts that need to be
63 considered as part of global management efforts. Likewise, major differences exist in the impact
64 of global or regional changes between developed, emerging and developing economies.

65 This paper has been prepared for the conference "Future Challenges to Food Safety",
66 organised by the Dutch Food and Consumer Products Safety Authority (VWA) and the European
67 Food Safety Authority (EFSA), held in Wolfheze, The Netherlands, from 9 to 12 June 2008. It
68 explores current and potential future trends in the foodborne disease burden around the globe as
69 they relate in particular to technology, consumption and trade of certain foods that are likely to
70 impact on microbial food safety. Developments in food technology and significant changes in
71 consumer demand and food trade around the world over the next decade are discussed. To
72 identify trends and underlying drivers, a system-based approach is taken which analyses how

73 different drivers currently impact in broad terms on a system of interacting driving factors
74 representing the food system. In so doing, the impact of potential future events on food
75 technology, international trade and consumption is explored. The paper endeavours to present a
76 global perspective on trends influencing the burden of food-borne disease, while taking many
77 examples from the European Union (EU) and its Member States.

78

79 2. Method of Analysis.

80

81 2.1. *Methods for exploring the future.*

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

97 developments), whereas others (e.g. a major outbreak of food-borne disease influencing
98 consumer choice) can impart a specific step change.

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

107

108 *2.2. Defining the investigation focus.*

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

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

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

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

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

147 Hughes et al. (2007) used data from food-borne disease outbreaks of infectious intestinal disease
148 in England and Wales (1992-2003) to categorise the food vehicle associated with outbreaks.

149 Common pathogen–food vehicle combinations identified were:

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

155 It should be noted that this study only considered outbreaks of infectious intestinal disease
156 and that the data did not include outbreaks involving *Listeria monocytogenes*, an important food-
157 borne pathogen in terms of mortality according to the Chief scientist’s report (FSA, 2007a). In
158 the few outbreaks in England and Wales, food vehicles for *L. monocytogenes* have included
159 sandwiches, dairy and meat products (McLauchlin et al., 1991; Gillespie et al., 2006). Elsewhere,
160 the prominent role of this pathogen in foodborne illnesses has been well recognised (BIOHAZ,
161 2007; Ontario MoH 2009).

162 Lynch et al. (2006) examined food-borne disease outbreaks in the USA between 1998 and
163 2002 and presented data by food vehicle (where known) and pathogen. Whilst some associations
164 are similar to those seen in the outbreak data in England and Wales there were also some
165 differences, such as the relatively high proportion of outbreaks associated with complex foods
166 such as desserts in the UK where it can be difficult to determine the origin of the contamination
167 (Adak et al. 2005).

168 3. Results.

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

177

178 3.1. Political Drivers.

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

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

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

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

203

204 *3.2. Economic Drivers.*

205 The World Bank estimates that 1.25 billion people live on less than \$1/day with 840
206 million of them suffering under-nutrition or hunger (Thompson, 2007). Some three billion people
207 live on less than \$2/day, which generally buys enough calories to offset hunger. As incomes rise
208 from \$2 to about \$10 per day, people eat more meat, dairy products, fruits, vegetables, and edible
209 oils, causing rapid growth in demand for raw agricultural products. Beyond \$10 per day, people
210 buy more processing services: packaging, variety, and luxury forms. Table 3 illustrates the huge
211 potential for poverty reduction in populous key emerging economies and developing countries.
212 The potential market growth for value added products is greatest in countries such as China and
213 India, where there is a huge potential for further population growth as well as poverty reduction.
214 Both population growth and the proportion of presently low-income consumers that are lifted out

215 of poverty will be important determinants of the future global demand for food. The World Bank
216 estimates that the number of people in developing countries living in households with incomes
217 above \$16,000 per year will rise from 350 million in 2000 to 2.1 billion by 2030. If there is a
218 50% increase in the world population plus a 50% increase in broad based economic affluence in
219 low-income countries, then world food demand could double by the year 2050.

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

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

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

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

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

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

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

284 eggs, which are food groups that have been more frequently associated with microbiological
285 foodborne illnesses in recent years.

286 A breakdown of the gross human apparent meat consumption per capita by animal is
287 shown in Figure 5B. It reveals that changes in poultry and pork consumption were responsible for
288 the increase observed in meat consumption overall, whereas consumption of sheep and goats, and
289 cattle declined. It is notable that the types of meat for which consumption increased also
290 experienced the most significant price falls in real terms (see Table 2C for changes between
291 1996 and 2002) and this would certainly have been a key factor in the observed shift in
292 consumption patterns.

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

303 In cases where food prices are higher due to increased demand, the difference between
304 costs and commodity prices should increase and some of this difference could boost farmers'
305 income. In contrast, where food prices are higher due to increased production costs, this could put
306 downward pressure on farmers' income. The former case would represent an opportunity for

307 agricultural investment, and indeed, investment could be encouraged in areas beneficial to
308 microbial food safety.

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

315 The food supply network has seen numerous changes that enable the food supply network
316 to benefit from economies of scale, with consolidation of, for example, suppliers of agricultural
317 inputs (Tansey, 2008) and retailers (UK Prime Minister's Strategy Unit, 2008). Moreover, there
318 has been greater co-ordination between companies, both those interfacing vertically in the supply
319 network, and, in the agricultural input sector, horizontally via alliances between companies in
320 similar fields (Tansey, 2008). Structural changes within this supply network have been occurring
321 and this is likely to continue. If these changes and their implications for microbial food safety are
322 not fully considered and managed, there is the potential for a significant impact on public health.
323 Worldwide there are already examples of outbreaks of huge magnitude. In 1988, a Hepatitis A
324 epidemic in China associated with the consumption of clams affected 292,000 people, killing nine
325 of them (Rocourt et al., 2003). In a 1996 Japanese outbreak, at least 9,578 individuals (mainly
326 schoolchildren) suffered from severe *E. coli* O157:H7 infections linked to white radish sprouts
327 (Mead et al., 1999). In 2000, an outbreak from milk in Japan resulted in almost 6,000 illnesses;
328 the contamination point was a production line valve that became contaminated (Adak et al.,
329 2002).

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

333

334 *3.3. Social Drivers.*

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

346 Perceptions of food are influenced by a wealth of information of varying quality. For
347 instance, the United Kingdom public named the following organisations when asked who
348 provided their information on food safety and food scares: Government Departments,
349 supermarkets, local councils, food manufacturers, consumer groups and the media (FSA, 2007b).
350 Where accurate and balanced information on food safety is available to the public, there is the
351 possibility for self-control in the system relating to consumption of foods associated with a risk.
352 For instance, to an extent, the public seek to minimise their exposure to food-based risk and
353 access to information can aid this minimisation. An example of this is the reduction in foodborne

354 disease in Los Angeles after the hygiene ratings of restaurants were displayed at the entrances of
355 premises (Zhe Jin & Leslie, 2003). In this case, enforcement activities on accessibility of
356 information impacted on consumption behaviour and the foodborne disease burden.

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

370 Taking the UK as an example, consumers spend a greater proportion of their food budget
371 eating out than they have done in the past, although in the last 5 years, this trend has levelled out.
372 This reflects the increase in disposable income available relative to food prices (UK Prime
373 Minister's Strategy Unit, 2008). Although convenience is a strong driver, other preferences
374 relating to consumer behaviour are exerting themselves, such as an increasing desire for home-
375 cooking, and an associated aspiration to increase fresh ingredient usage (Datamonitor, 2006). It is
376 noted, however, that these desires are not often realised due to time pressures. This has led to the
377 recent development of products that facilitate 'meal assembly', i.e. the use of semi-prepared

378 ingredients to create a meal. The use of meat products, including marinated and semi-cooked
379 variants, has the potential to impact on foodborne disease if information on preparation, cooking
380 and storage is not clearly conveyed to or followed by the consumer.

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

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

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

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

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

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

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

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

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

463 Global food demand is closely linked to global population, which is predicted to rise from
464 6.6 thousand million people in 2008 to between 7.4 and 7.8 thousand million in 2020 (United
465 Nations World Populations Prospects, 2006). Thus, the world food demand is likely to grow
466 substantially over this period, not only from this rise in population, but also from an increasing
467 urban and affluent population in countries with emerging economies, as detailed by Schmidhuber
468 (2003) and typified by China and India in recent years. These trends will continue to exert an
469 upward pressure on food prices and could reduce the global availability of certain foods.

470 In contrast to the world population, Europe's population is predicted to be relatively
471 stable, reducing from 730 million in 2008 to 720 million in 2020 (reference as in previous
472 paragraph). Given that the EU is self-sufficient in many food types that may impact on foodborne
473 disease (e.g. Table 2A), this creates a degree of security of food availability in the future and a

474 moderating influence on food prices in Europe relative to global prices. As noted by the UK
475 Prime Minister's Strategy Unit (2008), it is the food-importing developing countries that are
476 likely to face the biggest challenges as a result of increasing world food prices.

477 Although the population of Europe is set to remain relatively constant, the age structure is
478 estimated to alter significantly, for example, predictions show that in 2020, 30% of Germany's
479 population will be 60 years old or above, compared with 25% in 2005 and 37% by 2050 (United
480 Nations World Populations Prospects, 2006). The susceptibility to and severity of many
481 foodborne diseases increases with age: e.g. the increase in listeriosis cases noted in several EU
482 countries in recent years has been seen mostly in the elderly population (Denny and McLauchlin,
483 2008; Goulet et al., 2008), and the proportion of *Campylobacter* cases requiring hospitalisation
484 has increased markedly in the patients over 75 years old (Gillespie et al., 2005). The reasons for
485 the increased severity and susceptibility are not fully understood but are likely to include a
486 lowered efficiency of the immune system and oxidative damage leading to ageing and increased
487 vulnerability to diseases related to the occurrence of cellular damage for instance due to the
488 action of reactive oxygen species. In addition, other physical and mental deterioration, food
489 choices and behaviours may play a role. Although physical deterioration is not solely determined
490 by age, it is likely that the increase in the population of older people will put upwards pressure on
491 the foodborne disease burden. It should also be noted that the food choices of tomorrow's older
492 people will not necessarily be the same as today's older generation.

493 Migration into and away from Europe will continue to be affected by EU expansion,
494 relative income, perceived quality of life, immigration rules and the extent of conflict zones
495 around the world. The future trajectory of these drivers is hard to predict, but they are likely to
496 influence the food preferences within Europe. If immigration causes a major shift in food

497 consumption and preparation techniques, it is possible for this to alter the burden of foodborne
498 disease.

499

500 *3.4. Technological Drivers.*

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

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

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

532 Of the preservation technologies that are novel in terms of practical application, HPP has
533 probably advanced further than any of the other alternative physical food processing
534 technologies. One of the major processing advantages is that pressure is transmitted uniformly
535 and instantaneously throughout the food product, therefore there is no gradient of effectiveness
536 from outside to inside as there is with thermal processing. Due largely to the advancement of the
537 engineering of the equipment, HPP has become an economically viable process in the last decade
538 or so. Today, high pressure ‘pasteurization’ has become a commercial reality with over 120
539 commercial operations worldwide. Several fruit- and vegetable-based refrigerated food products
540 are currently on the international market, including a range of juices and fruit smoothies, jams,
541 apple sauce-fruit blends, guacamole and other avocado products, tomato-based salsas and fajita
542 meal kits containing acidified sliced capsicum and onions and heat and serve beef or chicken
543 slices (acidified and precooked). Additionally, ready-to-eat meat products and seafood, including
544 oysters, are on the market in the U.S. and Europe (Smelt, 1998; Stewart and Cole 2001). The use

545 of HPP for the pasteurization of sliced meats is an excellent example of how the technology can
546 be used to both enhance food safety and meet consumer trends. The technology provides a robust
547 in pack pasteurization with respect to *L. monocytogenes* with relatively little impact on product
548 quality. It also allows manufacturers to eliminate preservatives from the formula and to be able to
549 make an ‘all natural’ claim in the US. Another potential for the technology is in the inactivation
550 of foodborne viruses in shellfish (Grove et al., 2006). HPP uses pressures of approximately 300 to
551 700 MPa for a few seconds or minutes to destroy vegetative microorganisms, and can be thought
552 of as a “cold pasteurization” process. Typically, 10 min exposure to HPP in the range of 250-300
553 MPa or 30-60 sec exposure to HHP in the range of 545-600 MPa exerts a pasteurization effect
554 (Hoover, 1997). Notably, microorganisms are quite variable with regard to their sensitivity to
555 HPP. Results of experiments conducted by Shigehisa et al. (1991) suggest that the order of
556 sensitivity to HPP is Gram-negative bacteria > yeasts > Gram-positive bacteria > bacterial spores.
557 Bacterial spores are actually highly resistant to HPP, even to pressures of up to 1000 MPa
558 (Timson and Short 1965; Sale et al., 1970; Cheftel, 1992), and hence a combined treatment of
559 parameters such as pressure, mild heat and low pH is typically required for inactivation and
560 control of outgrowth.

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

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

576 Perhaps one of the oldest and most studied non-thermal technology is food irradiation,
577 which is approved as a food processing method in 43 countries including the U.S., the UK,
578 Belgium, France and the Netherlands. There is an extensive amount of information available in
579 the literature about food irradiation, including reviews by Radomyski *et al.* (1994), Monk et al.
580 (1995), Farkas (1998) and Barbosa-Canovas et al. (1998). There are currently two main methods
581 of producing the ionizing radiation sources for food applications: gamma radiation and electron
582 beam radiation. Gamma radiation is the traditional radiation method and the radioisotope used in
583 most commercial facilities is cobalt 60. The mechanisms for microbial inactivation by irradiation
584 are well known. Irradiation irreversibly damages microbial DNA leading to the inability of the
585 organism to reproduce. There are over 45 years of extensive studies documented in the scientific
586 and technical literature detailing chemical and microbial effects of irradiation of food and
587 reporting decimal reduction times (D_{10} -values) for most foodborne pathogens and many food
588 spoilage organisms. A data analysis of D_{10} -values achieved with irradiation for bacteria and
589 spores has been undertaken and provides approximate estimates of this parameter that can be
590 useful in designing and evaluating irradiation processes under various conditions (van Gerwen et
591 al., 1999). The World Health Organisation has approved irradiation dosages for foods of up to 10

592 kilograys (kGy) as “unconditionally safe for human consumption”. Despite this, the key
593 impediment for the commercialization of food irradiation is consumer acceptance. Technically,
594 food irradiation provides a highly effective mitigation measure for foodborne microorganisms
595 and its commercialization would be expected to have a profound effect on the incidence of
596 foodborne diseases globally. However, the consumer attitude to food irradiation is a complex
597 issue in which acceptance of the technology may ultimately be weighed against the risks of
598 illnesses due to foods. For example, acceptance of irradiated foods increased significantly when
599 the consumer was provided with information on the advantages of the technology in terms of
600 enhanced product safety and wholesomeness of the product (Bruhn, 1998). At the moment still, it
601 is very difficult to predict whether consumer acceptance would ever allow its commercial use in
602 mainstream food industry.

603 Innovations in our ability to assess and quantify harmful micro-organisms underly a quite
604 different area of technological drivers. The attribution of an adverse public health effect such as
605 illness to a particular pathogen requires detection of the particular pathogen, which might be at
606 the health care provider or local health department level. Investigation usually includes case
607 definition, symptoms and severity of the disease and an investigation of how illness occurs along
608 with sources of exposure. Surveillance helps to understand the trends in incidence of the disease
609 and role of specific foods. Surveillance is also important in the consideration of potential control
610 strategies by identifying which steps in the food chain could offer the most effective control
611 measures (Tompkin, 2007). Surveillance is crucial to monitor the impact of any resulting control
612 measures or public health policy (ICMSF, 2006). Advances in subtyping technologies (e.g.,
613 PFGE) and information technologies permit human and food isolates to be accurately matched,
614 resulting in the identification of foodborne outbreaks that until recently would have gone
615 undetected. In particular, the fields of 'omics' data generation, bioinformatics driven data analysis

616 and systems biology offer great opportunities for specific data generation to better understand the
617 resilience of microbial pathogens in foods and assess preservation targets. In combination with
618 new developments of detection systems for food-borne pathogens as well as the development of
619 new predictive models these fields hold the promise for significantly furthering our understanding
620 of the biological systems at hand both at the level of the microorganism but likely also at the level
621 of the host as discussed elsewhere (Havelaar et al, accepted; Brul et al., 2006, 2008).

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

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

641

642 *3.5. Regulatory and Trade Drivers*

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

661 Developments in the areas of predictive modelling and risk assessment now offer the
662 potential to link characteristics of the food chain and the microbial hazards to the exposure and

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

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

687 Infants and Young Children (CAC, 2008). This code addresses the emerging public health threat
688 of *Cronobacter* spp. (previously referred to as *Enterobacter sakazakii*), which was brought to the
689 attention of Codex Alimentarius in 2002/2003 who then asked FAO and WHO (World Health
690 Organisation) to convene an expert consultation on the topic in February 2004 (FAO/WHO,
691 2004). The consultation used risk management principles to look at a range of control strategies
692 during both manufacture and subsequent use of powdered infant formulae that could be
693 implemented to reduce risk. Importantly, the approach facilitated the formulation of urgent advice
694 to different stakeholders, including caregivers of infants, consumers and industry and ultimately
695 led to a timely update of the code in 2008 (CAC, 2008).

696 Alongside the proportion of different food types being consumed, the origin and
697 production method are also important to microbial safety. Where food comes from is determined
698 by another set of inter-connected factors which include development of trade links, levels of
699 import tariffs, geographic proximity of exporter and importer countries, transport costs, exchange
700 rates, and relative costs for production, manufacturing and storage costs. Trade links, which are
701 closely connected to import tariff levels, develop over a relatively long time-scale. In contrast,
702 exchange rates can fluctuate on a much shorter time scale (hours or days), influencing choice of
703 supplier, although variability is reduced by the practice of agreeing fixed exchange rates for the
704 duration of contracts. The importance of geographical proximity is determined by the type of
705 food (e.g. stability, durability), transportation and storage costs, and social acceptability of
706 transportation over longer distanced versus local production. Recent negotiations relating to
707 global trade are, in general, reducing the level of import tariffs and liberalising global trade. One
708 example is development of the Economic Partnership Agreements between the EU and members
709 of the Africa, Caribbean and Pacific group. These would allow specified countries quota-free and
710 duty-free access to the EU markets. Although this has the potential to radically increase the

711 amount of food imported into the EU, in practice it is likely that change will be gradual as many
712 of the relevant exporter countries do not have the capacity to fill their current quotas (Stevens et
713 al., 2008). Furthermore, imports in food types important from the perspective of microbial safety
714 (i.e. foods of animal origin) are relatively small compared with apparent consumption in the EU
715 whereas the trade in fresh produce in the region is significant.

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

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

727

728 *3.6. Environmental Drivers.*

729 The predicted doubling in the global demand for food by 2050 will increase the need to
730 use more land for agriculture. Of all the potentially arable land, currently only around 12% is not
731 forested or subject to erosion or desertification. One way to meet the future demand for food
732 would be double the area of farm production, but this would have catastrophic effects on the
733 environment through destruction of forests and loss of wildlife habitat, biodiversity and carbon
734 sequestration capacity. Options such as making non-arable land arable or rework eroded land to

735 arable may not be readily feasible. The only environmentally sustainable alternative is therefore to
736 double productivity on the fertile, non-erodible soils already in crop production. The same forces
737 will also see the demand for products from forests increase and at the same time biofuels
738 production is claiming more and more land (Global Environment Facility, 2002).

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

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

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

758 are managed. Aside from agriculture, increased sea temperatures are likely to put further strain on
759 aquaculture (International Panel on Climate Change, 2007).

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

771

772 4. Discussion.

773
774 The coming decade is likely to see more challenges, and as a consequence changes, in the
775 food system than has been experienced in the recent past. By understanding the system
776 surrounding food consumption and trade, we can gain an insight into the associated impacts on
777 microbial food safety. This provides a useful first step for planning, development of strategies,
778 and prioritisation of actions.

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

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

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

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

823 Overall, increased consumption of certain food commodities known to be associated with
824 foodborne microbial hazards will increase foodborne illness with a reasonably high degree of
825 certainty. Examples here would include meat and poultry, driven by an increased ability to pay
826 for high protein foods and fresh produce, driven by a trend towards health. Another factor that
827 could increase burden of foodborne diseases, but with less certainty, is the increase in refrigerated
828 foods and extended shelf-life foods driven by a trend towards the desire for convenient foods.
829 The use of effective regulatory measures is considered a factor in our ability to reduce the food
830 borne disease burden with a reasonably high degree of certainty given past experience. Other

831 factors important to the ability to reduce the burden of foodborne diseases are the development
832 and use of new food safety technologies and detection methods. The most important factor in
833 reducing food-borne disease is likely our ability to first detect and investigate a food safety issue
834 and then to develop effective control measures.

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

850 The trends signalled underscore the importance of having reliable surveillance data and
851 systems regionally or even globally, as these could help to monitor new threats and to respond
852 quickly, but also would assist tracking the success of newly introduced control measures.
853 Considering the global context, a notable initiative that the WHO has established is the
854 Foodborne Disease Burden Epidemiology Reference Group (WHO, 2008) which has been set-up

855 to estimate the global burden of foodborne diseases. Given the growing reliance on food imports
856 from both developed and less developed countries, it is a challenge for national governments to
857 protect their consumers while facilitating fair trade. Conceivably, a country cannot solely rely on
858 its own food safety management systems but would best share best practices and experiences in
859 food safety management with its trading partners. In this regard, international standard setting
860 bodies such as Codex Alimentarius might play a helpful role by the development of equivalent
861 food standards aimed at reducing the burden of global diseases and facilitating international trade
862 in food.

863

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1098 **Legends of Tables**

1099

1100 Table 1. Estimated proportion of indigenous foodborne disease, by food group and type for
1101 England and Wales, 1996-2000 (source: Adak et al., 2005).

1102

1103 Table 2. Summary of economic indicators for several food groups. A. self-sufficiency of meats in
1104 2002 for the EU15 (Source: Eurostat accessed, 2008a); B. price elasticities by food group in the
1105 UK for all income brackets. (Tiffin, Arnoult and Irz, 2007); C. price change of meat by type
1106 (1996-2002, EU15), adjusted for inflation (Source Eurostat, 2008a).

1107

1108 Table 3. Population density data (multiple of million inhabitants) for several countries with
1109 indication of population fraction with income levels below 1\$/day and < 2\$/day (source: Source:
1110 World Bank, 2005).

1111 **Legends of Figures**

1112

1113 Figure 1. Selection of driving factors in different categories that influence consumption of a
1114 single food type.

1115

1116 Figure 2. Visual representation of the key factors likely to impact on foodborne disease. Whether
1117 factors are likely to increase or decrease the global burden of foodborne disease is plotted against
1118 the certainty of their impact.

1119

1120 Figure 3. Price elasticities in food in Great Britain for mid-income bracket showing the median
1121 (O) with error bars representing one standard error of the mean (Chesher and Lechene, 2002).

1122 .

1123 Figure 4. A (Left panel): factors other than demand affecting the food supply price; B (right
1124 panel): influences on demand of consumption of a single food other than price and income.

1125

1126 Figure 5. A (top panel): gross human apparent consumption (mass) per head of selected major
1127 food groups in the EU 1991-2003; 4 B (bottom panel): gross human apparent consumption per
1128 head of population in the EU of various types of meat (1995 to 2002), indexed to 1995 level.

1129 From Eurostat: agriculture and fisheries statistics (Eurostat, 2008).

1130

Figure 1. (Quested et al.)

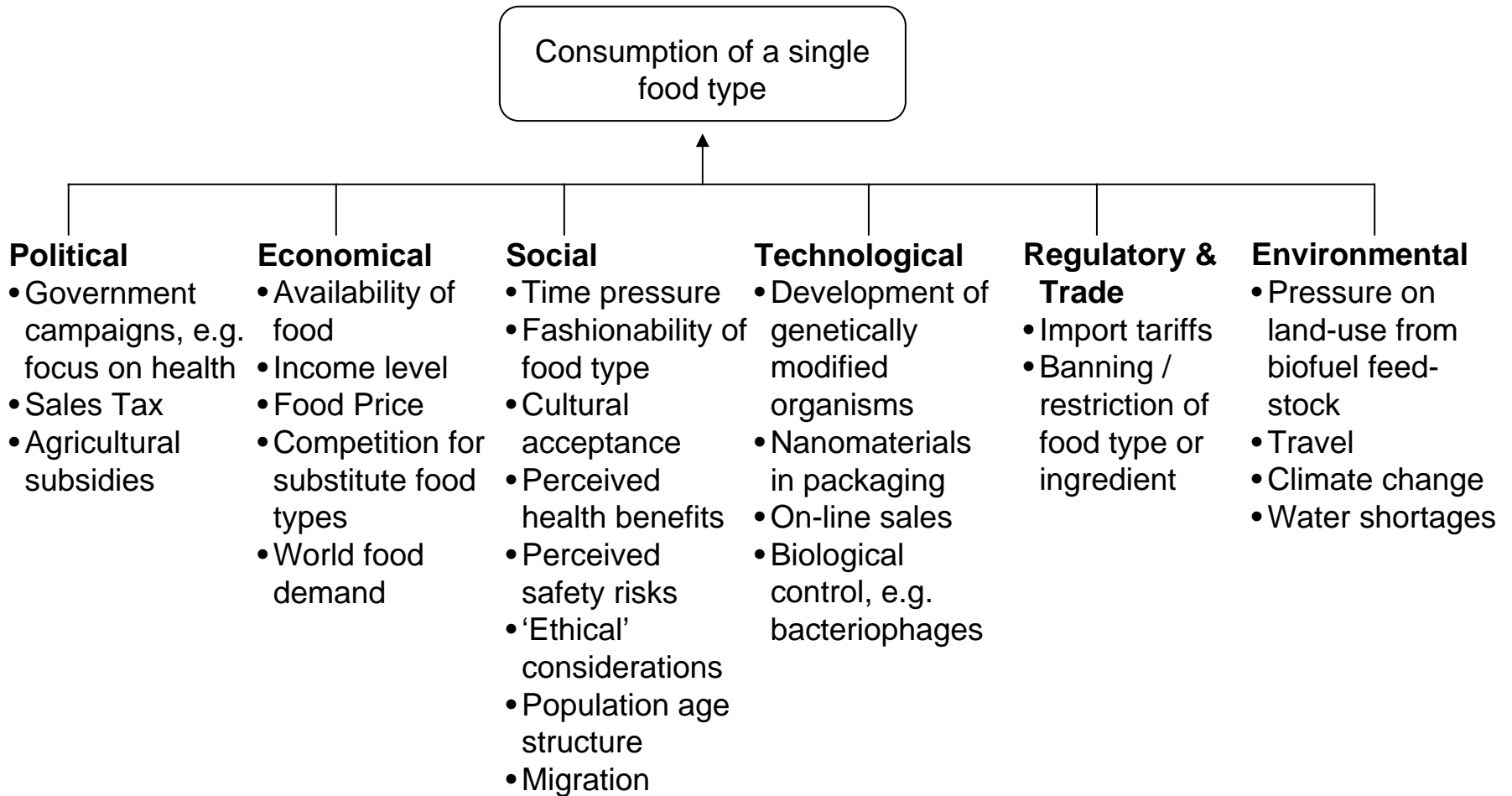


Figure 2. (Questaed et al.)

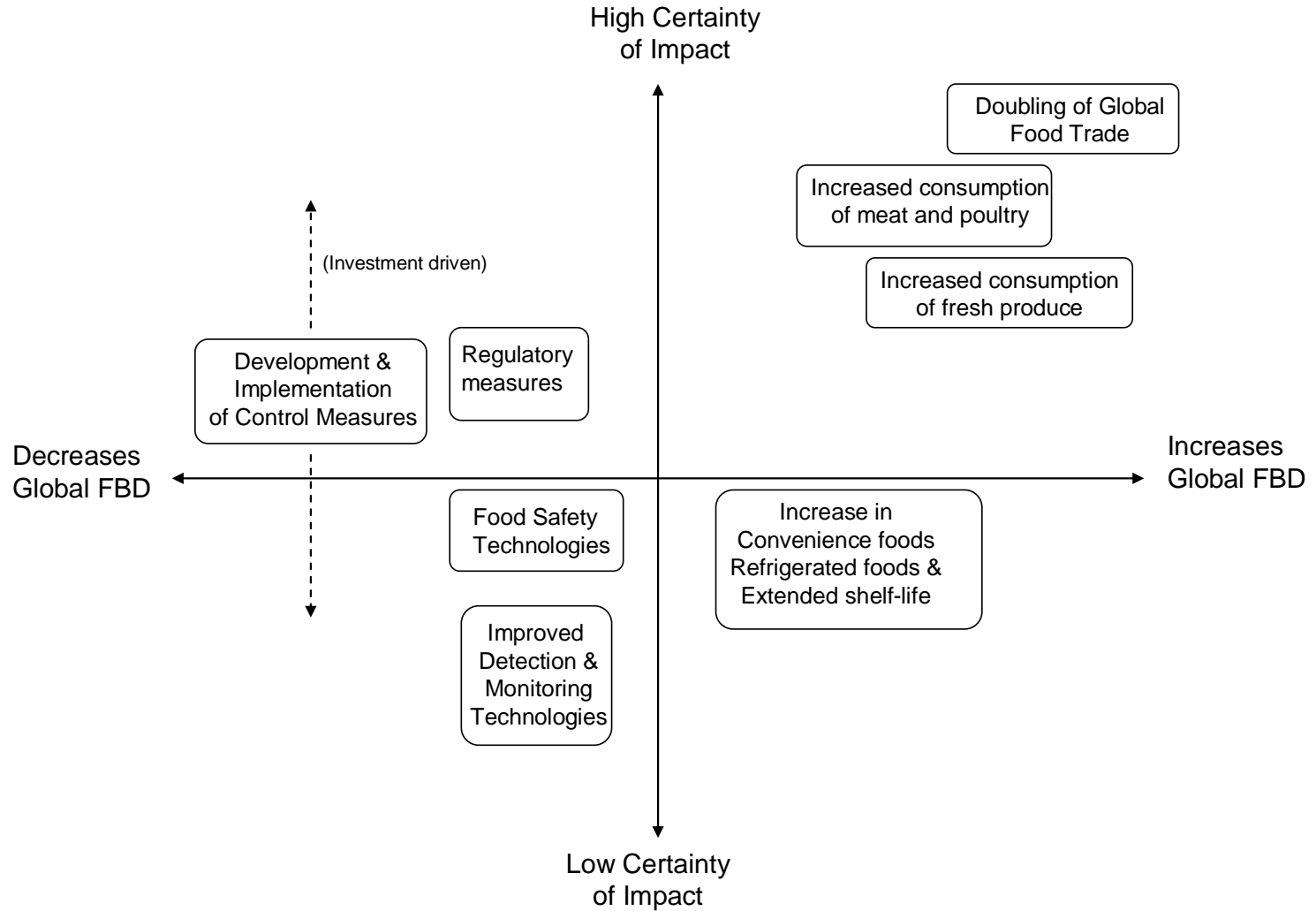


Figure 3. (Questaed et al.)

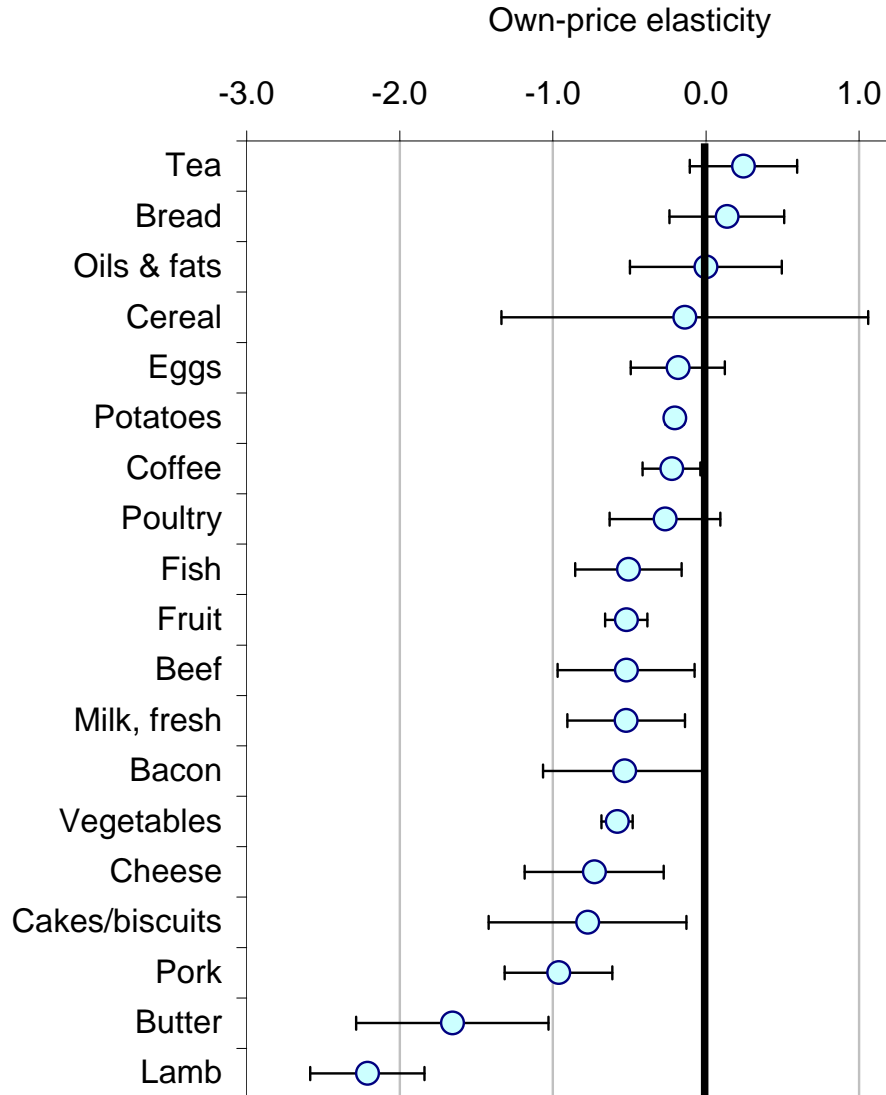


Figure 4A (left panel) and 4B (right panel) (Quested et al.)

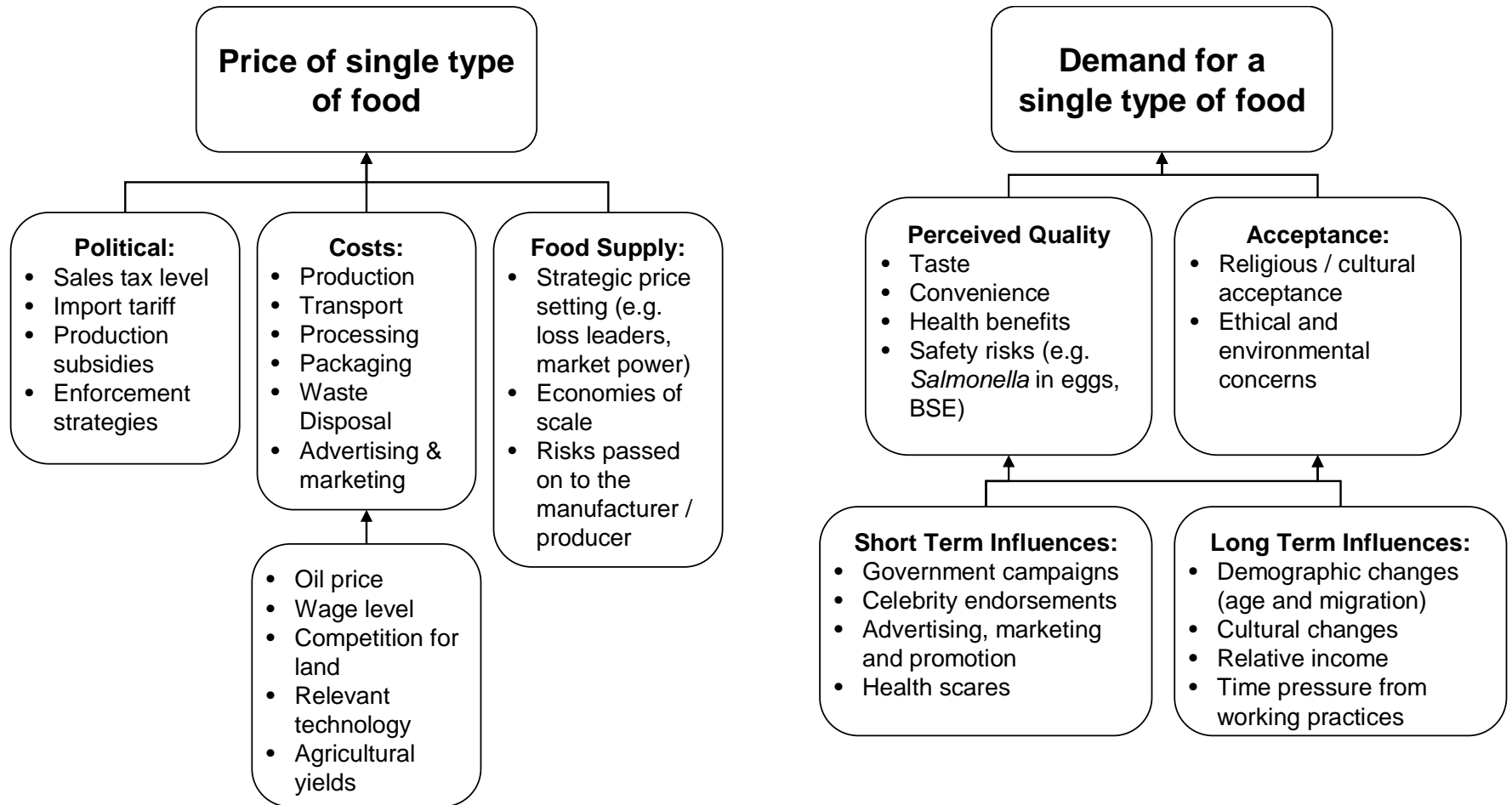


Figure 5A (top panel) and 5B (bottom panel) (Questaed et al.)

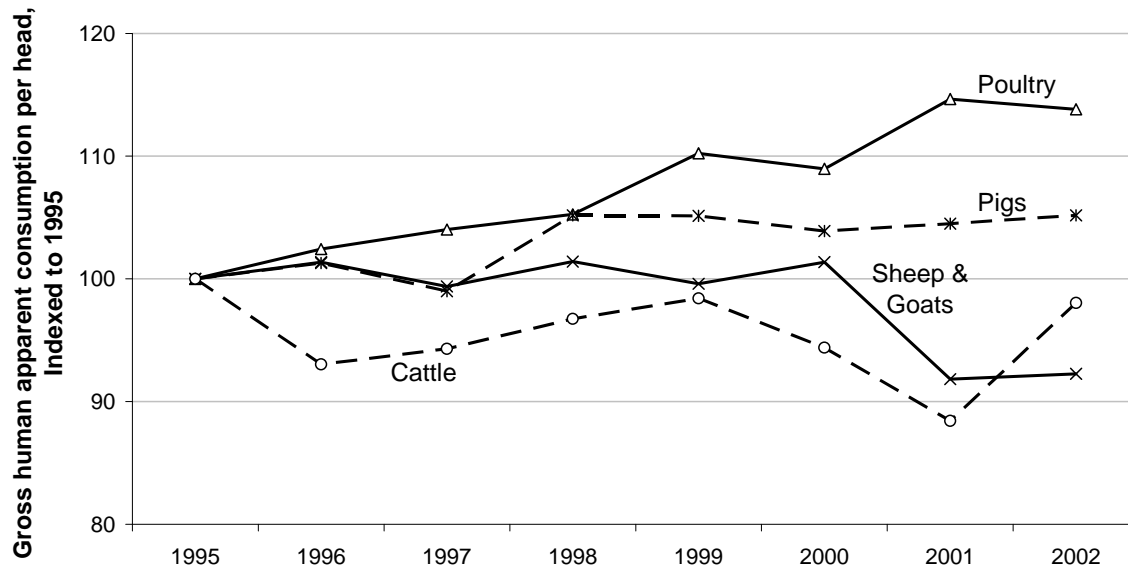
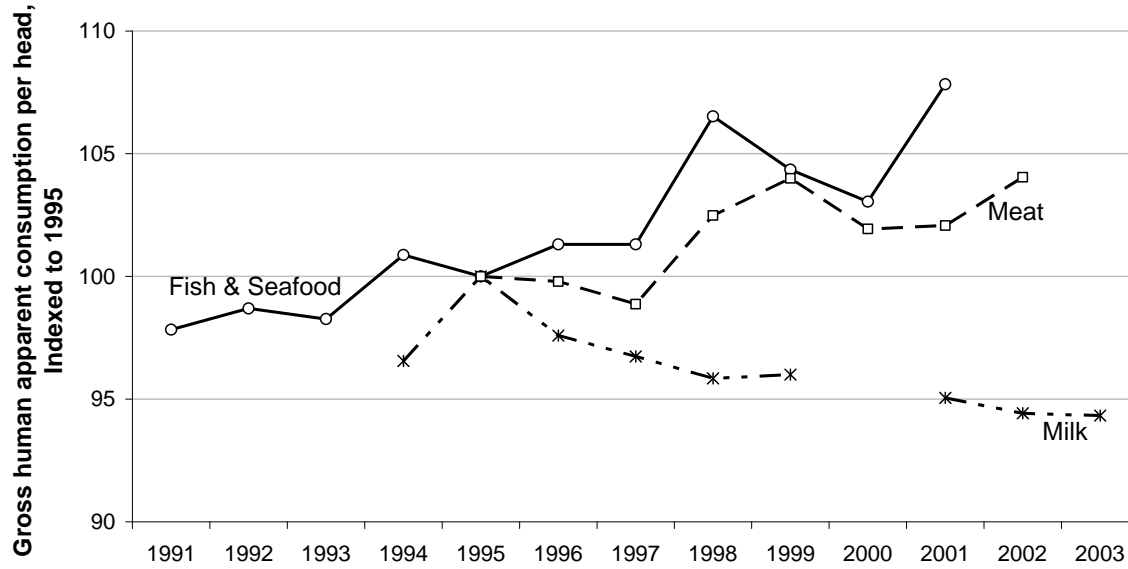


Table 1. Estimated proportion of indigenous foodborne disease, by food group and type for England and Wales, 1996-2000 (source: Adak et al., 2005).

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

Table 2 (Quested et al.)

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 elasticities 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 10⁶)	% < 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