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ORIGINAL RESEARCH

Is there a win–win scenario with increased beef quality and reduced consumption?

Louis-Georges Soler[1] · Alban Thomas[2]

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Abstract

In the scientific literature, the debate on health and environmental benefits of a reduction in the share of animal-sourced food, in particular beef, in consumer diets is mostly focused on demand-side versus supply transitions. We discuss in this paper the necessary conditions for a win–win scenario to exist, where consumer preferences for diets with less red meat are accompanied by a transition in livestock production systems towards higher average quality of beef. Trade-offs between quantity and quality of beef at the consumer level and between domestic and international markets for producers are presented, as well as the determinants of reduced beef consumption, productivity gains, innovation in quality and environmental impacts in the case of France. We present a simplified model of aggregate consumer surplus and producer profit, with decisions on beef demand, output price and quality, to explore the necessary combination of changes in consumer preferences, producer strategies and public policies, required to produce a win–win scenario. Our experiment provides conditions for a win–win scenario, including increased efficiency on domestic and international beef markets and enhanced consumer awareness. We suggest research priorities and policy recommendations for accompanying transition in food preferences and cattle production system.

Keywords Beef consumption · Food system · Demand for quality · Agricultural exports · Product innovation · Numerical simulation

✉ Alban Thomas
Alban.Thomas@inrae.fr

Louis-Georges Soler
louis-georges.soler@inrae.fr

[1] INRAE, 75007 Paris, France

[2] Toulouse School of Economics-Research, INRAE, University of Toulouse, 31000 Toulouse, France

Introduction

There is clear evidence over the past decades of an increase in world demand for animal products, in general, and bovine meat, in particular (Masters et al. 2016). However, several developed countries recently experienced a sluggish or declining trend in the consumption per head of these products. Even though such decline seems moderate for the time being, there is a growing discrepancy between the global outlook of meat consumption worldwide and the more "local" perception of the need to modify our food systems to address climate change, health and biodiversity issues.

In the scientific literature, there is an ongoing lively debate on the expected benefits of a reduction in the share of animal-sourced food in consumer diets (see, e.g. Willett et al. 2019; Springmann et al. 2016; Pérignon et al. 2017; Godfray et al. 2018). Such benefits are likely on health and the environment, and they extend to a limited pressure on natural resources as well as gains in animal welfare. An associated issue is the sustainability of a generalized "western" diet worldwide, characterized by a high meat content (Tilman and Clark 2014; Willett et al. 2019). The debate is often presented in global terms (world food security), but there are also local or national motivations for reduced bovine meat consumption and production, while heterogeneity in production practices and diets across countries and population categories is seldom accounted for. In addition, even though there is a general agreement on the need for a transition in present food systems, to cover the food requirements of a growing population while satisfying sustainability objectives, the description of the transition towards modified food systems along these lines remains lacking.

Transition in food systems towards less animal-sourced foods may be initiated by changing trends in consumer demand, to which producers have to adapt with possible public policies accompanying transitions in production practices. Indeed, there is some evidence that adaptation of existing production systems will not be enough to cope with impact of climate change and that a drastic change in consumer choices and diets is required (more or less urgently and more or less stringently) (Springmann et al. 2018; Poore and Nemecek 2018). Several options are then available, if one has a view of an" optimal" meat consumption level that is lower than the existing one. The first one is to accompany consumers towards more sustainable diets with dedicated demand-side policy instruments, like environmental labelling or taxes. The second one is to implement policy instruments on the supply-side to help producers react to decreased demand for meat (production quality innovation, market diversification, productivity gains…).

One possible scenario, where changes in consumer preferences towards more quality beef in diets are accompanied by a transition in livestock production systems, may correspond to a new equilibrium in the quality of beef. Such an equilibrium would be characterized by a lower beef consumption per head, but of higher quality, as well as a lower environmental impact. Is this equilibrium better (or at least neutral) for consumers in terms of welfare gain and for the producers' profit? Given the costs and benefits for producers and consumers, and given the public health and environmental impact, is this scenario social welfare improving?

The main objective of the paper is to deal with this scenario of quality/quantity substitution in beef production and consumption and to determine to what extent it can lead to a "win–win" equilibrium in which (i) both consumer surplus and producer profit

are at least equal to, or greater than, the situation before the decrease in red meat consumption, and (ii) the environmental impact of red meat production has been significantly decreased.[1]

The paper is organized as follows. In "Demand-side considerations", we focus on the demand side and the drivers of beef meat consumption changes. On the basis of available scientific literature, we discuss the extent to which a reduction in bovine meat consumption for a European country such as France may occur in the near future, and we identify the main consumers' trade-offs that are necessary to take into account. "Supply-side considerations" is dedicated to the reaction of the supply side in a single country, i.e. on the domestic market, following a decrease in beef demand. We explore different supply strategies, including improved competitiveness and development of international markets, innovation in quality and public policies for accompanying the transition of agricultural systems. In "A simulation experiment", we present a simple model to illustrate some economic mechanisms that must be taken into account to analyse the effects of a decrease in red meat demand, and we determine under which conditions a win–win scenario could happen. "Concluding remarks" concludes with a discussion on conditions underlying a successful transition towards a win–win scenario and with recommendations for future research.

. Demand-side considerations

Given the current demographic and income trends, it is likely that the global demand for animal-based proteins and meat will continue to increase in the next decades, driven by changes in dietary patterns in developing countries (FAO 2018). However, regarding developed countries specifically, some authors suggested that the Kuznets curve (Stern 2004), describing an inverse U-shaped relationship between pollution and income, could be applied to meat consumption. In a first phase, meat consumption increases as income increases; beyond a turning point, meat consumption could decrease, as people become more aware about health or environmental issues. Above a certain level of income, dietary patterns would shift towards more plant-based products (Vranken et al. 2014). Is there any evidence of such a shift in consumers' diets leading to lower meat consumption in developed countries? What are the main drivers of meat consumption and the main consumers' trade-offs we have to consider for discussing future meat demand trends?

A slow increase in consumer awareness about red meat and the environment

Changes in food consumption practices that have occurred in the last decades in developed countries have been extensively described. One major change is related to the strong increase in the consumption of processed foods and ready-to-eat meals, meat being much more consumed as an ingredient in prepared meals (at home and in food-

[1] Such a "win-win" scenario is not in itself a relevant economic goal, as it is not necessarily the best option in terms of social welfare increase. However, if one wishes to deal with the "system transition" issue, it is important to also consider the political acceptability of the changes required on the demand and supply side. A "win-win" scenario could be a first step of a more long-term scenario of social welfare maximization.

away from home) than directly cooked at home. This change makes it much more difficult to estimate actual meat consumption, leading to unclear conclusions about the current trends.

In France, for instance, a recent study based on consumer surveys shows that the average quantity of meat consumed per inhabitant decreased from 153 to 135 g/day between 2007 and 2016, this reduction being mainly due to the decrease in processed meat (from 35 to 29 g/day) and red meat (from 58 to 46 g/day) consumption (Tavoularis and Sauvage 2018). The frequency of meat consumption has also decreased, from 11.8 to 10.1 times a week over the same period, this trend being mainly due to processed meat (from 3.8 to 3 times a week) and red meat (from 3.2 to 2.4 times a week). Another study based on production and export/import data shows that red meat, pork and poultry consumption per inhabitant and year shifted from 26, 35 and 24 kg in carcass equivalent weight (c.e.w) respectively in 2007 to 23, 32 and 30 kg c.e.w. in 2018. Thus, red meat consumption began to decline in the mid-2000s (− 12% in 10 years), but this reduction has been compensated, at least in part, by an increase in poultry consumption (FranceAgrimer 2018a). Product substitution mainly occurred within the animal-based product category, leading to an overall stability of the total amount of meat consumption. Hence, if the reduction in red meat consumption seems to be well under way, the extent to which it could be compensated or not by an increase in the consumption of other meats versus meat substitutes is still a matter of debate.

To gain additional insights, recent studies have dealt with consumers' motivations about meat consumption in order to determine whether more radical changes could occur in response to environmental, health or ethical concerns. Most studies conclude on the strong heterogeneity of consumers' motivations about meat reduction, across and within countries (Apostolidis and Mc Leay 2016), which depend on sociodemographic characteristics and psychological, behavioural and cultural dimensions (Feucht and Zander 2017). Even if the increase rate of the vegetarians is high in many countries, it is a very small part of the European population and their will to remove totally meat products from diets is mostly driven by concerns linked to animal suffering (Hoffman et al. 2013). Flexitarians, that is, people who reduce or claim they wish to reduce meat consumption, are more driven by health concerns. In 2018, flexitarians represented 20% of the French population. Overall, Sanchez-Sabate and Sabaté's review (2019) shows that consumers willing to stop or significantly reduce meat consumption for environmental reasons are still a minority. Those who limit meat intake for environmental reasons are typically female, are young and would more likely live in Europe and Asia than in the USA.

In fact, several studies show that environmental issues are not, for now, strong drivers of consumer food choices. The first reason is that most consumers underestimate the environmental impacts, in terms of energy consumption or greenhouse gas (GHG) emissions, of the different types of food (Peschel et al. 2016; Camilleri et al. 2019). Mac Diarmid et al. (2016) explored public awareness about environment and consumers' willingness to reduce meat consumption. They show that a lack of awareness about the links between meat consumption and climate change and the perceptions of personal meat consumption playing a weak role on climate change limits the shift towards a lower meat intake. As a consequence, carbon footprint and production technologies play a secondary role in determining consumers' choices about meat (Apostolidis and McLeay 2016), while the type of meat, retail price, country of origin and fat content have the largest overall impact on consumer choices.

A second reason is that people associate eating meat with pleasure and taste, and they describe social, personal and cultural values around eating meat as important drivers of meat consumption (Weinrich 2018). In fact, for many consumers, changing personal behaviour is often viewed as more acceptable (Mac Diarmid et al. 2016) and a higher priority for climate change mitigation when it comes to non-food-related issues (transportation for instance) or non-meat-related issues. Thus, Bouwman et al. (2016) show, on the basis of a European survey, that most consumers prioritize seasonal, local and regional food, waste reduction and free-range and organic products rather than meat reduction to improve the environmental impact of food practices (Kause et al. 2019). This result is confirmed by another European study that shows that packaging and waste reduction, or a small increase in organic and plant-based products in diets, are much more prioritized than drastic changes in diet composition or a strong decrease in meat intake (Dubois et al. 2019).

Overall, if more people are concerned by the links between (beef) meat consumption, health and environmental impacts, the need to adopt diets with less meat is, for now, acknowledged by specific consumer groups, leading to moderate changes in the total quantity of meat consumption.

The consumer trade-off between quantity and quality

There are many sustainability certifications and labels for food products that focus on health, environmental or ethical benefits. These labels empower consumers to make informed purchasing decisions that take these considerations into account. Many studies have dealt with the motivations and price premiums that consumers are willing to pay for such quality and environmental labels. However, very few have tried to link quantity and quality decisions. In fact, a reduction in meat consumption may be associated with a "quantity/quality substitution", a lower quantity of purchased meat being associated with a higher quality in terms of sustainability (and higher prices). Is there any evidence of such a substitution? The best example to illustrate this trade-off is related to organic consumption. Several studies have analysed consumers' motivations, diets and food expenditures, in relation to their involvement in organic consumption. For instance, Baudry et al. (2017) used a large cohort of 22,000 participants to identify food choice motives and dietary intakes of non-organic, occasional and regular organic consumers. It turns out that dietary patterns and food intakes vary deeply across these consumer groups. Compared with non-organic consumers, regular consumers exhibit dietary patterns that included more plant foods and less red meat, meat processed meat and milk.

Using large consumer panels recording food purchases, Boizot-Szantai et al. (2017) analysed the composition of food baskets and expenditures, depending on the share of the households' expenditures dedicated to organic food purchases. They analysed the average basket composition of each quintile of consumers along the gradient of increasing organic food expenditures. First, it turns out that, from the first quintile (non-organic consumers) to the last one (regular organic consumers), the greater the share of the food budget dedicated to organic food, the lower the quantities of meat, and processed foods, and the greater the quantities of fruits, vegetables and legumes. Second, the greater the share of the food budget dedicated to organic food, the greater the share of the food budget dedicated to other quality and sustainability labels (protected denominations of

origin, "Label Rouge" certification…) and then the higher the average price of each food group. Third, the reduction in meat intake (fresh red meat, processed meat, prepared meals containing meat…) compensate, to a large extent, the additional cost induced by an increase in fruits and vegetables, starchy products and legumes intakes. In addition, such changes in dietary patterns compensate, at least in part, the larger expenditures induced by more expensive and higher-quality products. This pattern is observed not only among regular organic consumers but also among occasional organic consumers, of course with a smaller magnitude. The growth in organic consumption observed in many countries, which seems to be associated with a reduction of meat product consumption, could indicate, even if it is still a low size effect, a possible and future pathway based on the substitution between quantity and quality.

The consumer trade-off between (red) meat and (red) meat substitutes

Red meat substitutes include other meats (poultry, pork), plant-based products or new substitutes like cultured meat or insects. Recent studies have dealt with consumers' motivations about these different meat substitutes, in order to determine whether more radical changes could occur in response to environmental, health or ethical concerns.

Weinrich (2018) compared reasons for consuming, or not, meat substitutes in Germany, the Netherlands and France. Taste preferences and sensory dimensions, eating habits and convenience appear to be frequent impediments to reducing meat consumption in favour of meat substitutes. In Norway, Austgulen et al. (2018), by combining consumer surveys and field experiments, found that providing information about climate benefits of eating less meat has an effect on vegetable purchases but not on meat consumption. More generally, a systematic review (Hartmann and Siegrist 2017) aimed at determining to what extent consumers were willing to substitute meat with an alternative, particularly insects and cultured meat. It turns out that willingness to replace meat with meat substitutes, insects or cultured meat, is low. Although people seem to be sensitive to health, environment and animal welfare, dimensions like taste, appearance and convenience are crucial drivers of their regular consumption.

Experiments have also been conducted to measure the impact of information on consumers' trade-off between red meat and plant-based protein substitutes. For instance, Castellari et al. (2018) evaluated the impact of different types of information on participants' willingness-to-pay (WTP) and quantity choices for both beef and soy burger meat. Participants were provided with explanatory messages regarding the impact of beef and soy on health and environment before successive rounds of WTP evaluation and quantity choices. Results showed a weak impact of successive rounds of messages on WTP for both beef and soy, while leading to higher relative variations in chosen quantities. Another experiment (Marette and Millet 2016) was conducted to deal with the effect of meat quality labels on the trade-off between meat and meat substitutes. When consumers have to choose between standard beef and meat substitutes, information on health and environment induces an increase, albeit small, in the meat substitute demand. However, when standard beef is replaced by high-quality beef, selected quantities return to the initial quantities, namely the ones chosen before the information message. This reversal of chosen quantities underlines the participants' sensitivity to beef quality and its impact on the trade-off between conventional meat and meat substitutes.

Conclusively, it can be mentioned that meat substitutes are still far from being established on a large scale because of cultural, sensory and convenience reasons. Consumers' awareness about health and environment may have a probably modest impact on meat substitute consumption, which will also depend on food innovations, leading to more appealing use of these substitutes. The magnitude of the substitution between red meat and meat substitutes depends on the producer efforts and guarantees about the nutritional and environmental quality of beef products.

Policy instruments

The main limitation to reduce meat consumption is clearly related to current consumer preferences (sensory and taste, food habits…), meaning that for most of them, moving from current diets to more plant-based diets induces a loss of welfare. Is it then justified to intervene in order to lead people to change their diets?

Irz et al. (2016) addressed this question by developing a model of consumer behaviour under dietary constraints, matched with an epidemiological model of diet-related mortality, and a life cycle analysis model of environmental impact. This approach allows for the ex ante assessment of dietary recommendations in multiple sustainability dimensions. It was applied in the French context to compare the relative effects and efficiency of various diet recommendations. Regarding the recommendations to decrease red meat and all meats intakes, it turns out that the welfare loss is much higher when consumers are told to decrease all meats rather than only red meat (because in this case, they may replace red meat by poultry or fish or milk products). But in both cases, the economic value of environmental and health benefits is much higher that the consumer welfare loss. This means that in a cost–benefit framework, it would be justified to recommend consuming less meat or red meat, as benefits exceed the consumer welfare loss. However, it also means that most consumers, given this welfare loss, will not shift towards less meat intakes and alternative diets without any policy intervention.

A first type of instrument is based on information and product labelling. Several analyses have recently addressed the question of ecolabeling as a driver for market differentiation on domestic (local or national) meat markets. Shewmake et al. (2015) study 42 food products including meat and explore the potential of carbon labels to reduce greenhouse gas emissions. They confirm that carbon labels are helpful in informing consumers that their beliefs about environmental carbon footprints matter. Carbon labels on meat would achieve the largest decreases in carbon emissions among the food items considered. Other studies deal with the nature of information to provide to favour a reduction in meat consumption. For instance, Carfora et al. (2019) assessed emotional versus information messages in experiments. Participants exposed to emotional messages reduced meat intakes at follow-up, while this was not the case for participants exposed to informational messages. Camilleri et al. (2019) found that providing consumers with information regarding the GHG emissions associated with the life cycle of food shifts their actual purchase choices away from higher-emission options. Thus, although consumers' poor understanding of the food system is a barrier to reducing energy use and GHG emissions, it also represents a promising area for simple interventions such as a well-designed carbon label.

Other instruments are based on price modifications, through carbon and meat product taxes. Caillavet et al. (2016) studied the effects of ad valorem environmental taxes on meat products in France. They show that they could reduce GHG emissions (by − 6.6 to − 13.2%) and improve diet quality (1.2%) with a modest impact on the food-at-home budget (− 4.0%). In a similar analysis in the UK, Revoredo-Giha et al. (2018) show that the net application of meat taxes is likely to reduce demand for beef and sheep products, irrespective of socioeconomic groups. Implementation of an all meat carbon consumption tax has the potential to reduce household demand for meat products, resulting in a likely 10% reduction in meat-related emissions. Bonnet et al. (2018) evaluated an excise tax, based on two different tax rates (56 euros and 200 euros per ton of CO_2-eq), and applied to the consumption of all animal products, only ruminant meats or only beef. The most efficient scenario would be to tax the consumption of beef only at a high level. Indeed, this tax policy would help reaching a 3.2% decrease in GHG emissions without generating a too large loss of consumer welfare. Kehlbacher et al. (2016) found that, in the UK, a carbon tax on all foods would reduce food-related emissions by 6.3%, and a tax on foods with above average levels of emissions would reduce emissions by 4.3%.

Overall, depending on the tax rate and the set of taxed foods, carbon taxes implemented at the consumption level may lead to a moderate decrease in GHG emissions from meat production, but they would induce welfare losses for most consumers. It is worth noting that the implementation of meat taxes at the consumer level is generally assessed without taking into account producers' reactions in price or quality. In addition, as mentioned by Zech and Schneider (2019), they omit possible increases of net exports that might offset such reduction in demand. For these reasons, a GHG emission tax on food products may be much less efficient than generally proposed, if it is not introduced globally or international trade is not considered.

To conclude this section, it is possible to identify a general trend towards a decrease in ruminant meat consumption, partially compensated by poultry and pork. Consumer switch towards other meat substitutes remains moderate and will depend on the sensory and convenience characteristics of innovations in this sector. Overall, the autonomous decrease in meat consumption remains modest and concentrated on some consumer groups. In general, consumer motivations are more related to health and animal welfare than to the environment. Some consumers, in relation to the increase in purchases of organic and sustainability labels, are experiencing the so-called substitution between quantity and quality by purchasing smaller quantities of meat, but of a better (environmental) quality. This raises questions about the possible reactions of beef producers and supply chains in response to a potential change in red meat demand, in quantity as well as in product quality.

Supply-side considerations

Demand-side considerations in the "Demand-side considerations" section dealt with the situation where bovine production technologies and the structure of supply were fixed (in the short run). In the medium run, bovine production technology and supply may vary, allowing farmers to design supply-side strategies based on innovation in product quality, consisting of, e.g. enhanced intrinsic quality of product and reduced

environmental impact. An important consequence is that, at the country level for an aggregate supply sector, a change in consumer demand for beef can be met by a producer price strategy leading to an increase in average quality. Faced with a reduction in bovine meat demand, cattle farmers have to adapt by designing production-side strategies. If not sufficient, the latter may be accompanied by public policies fostering transitions in production practices and cattle breeding systems. We discuss in this section supply-side strategies, relying first on the trade-off between beef quantity and quality and, second, on the trade-off between domestic and export markets. The section concludes by a discussion on policy instruments (taxes, subsidies, payments for environmental services) to promote and accompany structural changes in beef supply, given the demand.

Current trends

We consider France as an interesting case study for exploring supply-side strategies, because of its leading role in Europe regarding beef production, its quality sector for beef and an observed decrease in beef consumption per head (although with a still limited rate). Being in the European Union, France is subject to stronger animal welfare and sanitary requirements on production, transportation and processing than other countries, which can be an advantage on some international markets. Finally, research and development and extension services are available to accompany the required increase in productivity and in quality dimensions. Quality is understood here as a reduced impact of production systems on the environment and integration of animal welfare requirements.

Beef production represented about 9% (6.9 billion euros) of total French agricultural value (76.4 billion euros) in 2018, with male bovine and calves contributing respectively for 52 and 11% of total animal production value (excluding subsidies) in 2018. For the same year, cows represented on average 41% of total bovine weight, male bovine 31% and veal calves 12% (INSEE 2019). The total number of bovine heads produced in France is around 4.6 million, of which 1.2 million are calves, 2.3 million are female bovine and 1.1 million are male bovine animals. This corresponds to a total of 1.47 million ton of carcass weight equivalent (tcwe). In terms of exports, about 240,000 tcwe were traded for a value of more than 1 billion euros in 2018, with major importing countries being the Netherlands, Germany, Ireland, Spain, Italy and Brazil. At the same time, France is also importing bovine meat, about 333,000 tons, and exporting about 1.07 million grass-fed calves (mostly to Spain and Italy) and about 250,000 young (milk-fed) calves (mostly to Spain). The net estimate for beef consumption (slaughtered animals minus exports plus imports) was 1.56 million tcwe in 2018. Overall, the French trade balance for the beef and calf sector was positive and around 1.1 billion euros in 2018 (FranceAgriMer 2018a).

French beef production cost on export markets is higher than non-European competitors but not so much compared with other EU countries. Beef production costs are heterogeneous across French regions and type of product (milk-fed calf, veal calf, mal bovine, etc.). Sarzeaud and Becherel (2006) report average cost per 100 kg of live weight ranging from 114 to 197 euros (compared with, e.g. 57 euros/100 kg for Argentina, 160 euros/100 kg for Spain and 173 euros/100 kg for Germany). Operating cost estimates range from 159 to 436 euros /100 kg in Institut de l'Elevage (2012). Beef

production cost was estimated at 1269 euros per cattle head on average, feed representing 34% of operating costs, compared with a European average cost of 2304 euros per cattle head (DG Agri 2011). It is interesting to note that regarding marketing strategy, 3.6% of beef and 5.8% of veal meat were sold under four different quality labels in 2018 (FranceAgriMer 2018a), with a fast increasing trend for organic and origin labels.

The producer trade-off between quantity and quality: improving average quality of beef

In a first supply-side strategy, producers may increase the average quality level of supply, by including more environment-friendly production and animal welfare-enhancing breeding practices. High-quality beef can then be valued through food markets with a price mark-up, provided a consistent eco-labelling marketing strategy is designed to target consumers with a higher willingness-to-pay for quality bovine meat. Regarding the trade-off between quantity sold and quality, an increase in environmental monitoring (and animal health and welfare dimensions) of bovine meat processing may also result in better market performances, without a change in the structure of the processing industry. A higher quality on average results in this case from innovation in quality monitoring and the ability of suppliers to label their enhanced quality accordingly (see, e.g. Ahmad 2012; Fiala 2008; Shewmake et al. 2015).

Interest is growing in developed countries for beef production from extensive, pasture-based instead of grain-finishing feedlot systems, which may be considered "higher-quality" cattle production systems. As documented by Hayek and Garrett (2018), accounting for cattle herd dynamics is needed to have a more consistent assessment of the environmental impacts of transitions in livestock production systems. They show that in the USA, a transition from grain- to exclusively grass-finishing systems would require increasing the national cattle herd from 77 to 100 million cattle. Liu et al. (2009) discuss the role of marketing arrangements in the improvement of beef quality. These include better vertical coordination, a more precise price signalling strategy (through the use of different cattle categories), and valuation methods based on information exchange mechanisms between producers and consumers. Based on data for marketing arrangements and cattle purchase data in the USA between 2002 and 2005, their results indicate that fed cattle procured through marketing agreements, especially fed cattle valued using carcass weight with a grid, has a higher quality than with other types of arrangements.

France AgriMer (2018b) proposes a foresight exercise on the future of the beef sector based on expert opinions, on various dimensions including international market outlook, biotechnical (genetic) innovations, quality signalling, animal welfare concern in the French population, organization of the beef value chain and price of energy etc. The report suggests five major scenarios, including limitation of greenhouse gas emissions, rise in red meat quality due to strong health and environmental constraints and an innovative and structured beef sector with segmented supply in a buoyant world market for beef. A scenario compatible with environmental constraints and animal welfare regulation would lead the French beef sector to a more concentrated production system in terms of capital, agricultural and processing labour, while the grass-fed system intensifies with a greater use of fodder than pasture. Such scenario would also

be facilitated by genetic innovations and payment schemes for environmental services provided by pasture (see below).

Conversion cost estimates are essential in the construction of policy policies to accompany transitions of agricultural systems. In the case of France, data are not easily found regarding conversion to more extensive production practices and breeding systems for a wide range of regions and cattle. However, even though complete symmetry in conversion costs may not be the case, conversion cost estimates are available in the opposite direction, i.e. from extensive to more intensive systems. Rossi et al. (2014) present a study on extensive fodder and grass-fed livestock systems, by considering the major determinants of economic viability and including market opportunities for 12 representative French livestock systems. From a mixed approach of modelling and analysis of expert opinions, a simulation exercise provides cost estimates for the conversion of pasture to crop land, farmland expansion, diminishing or increasing livestock and even full conversion to cereal production (giving up cattle breeding). Cost estimates range from 18.22 euros/ha for conversion of temporary pasture to cereals in the Charolais production area of central France to 113.87 euros/ha for conversion of permanent pasture to cereals in Normandy.

To conclude on this strategy, the potential for the livestock sector to develop a strategy based on enhanced quality depends on consumer preferences (see "Demand-side considerations") and on conversion and operating costs. These costs are essential to evaluate because quality improvements presumably have heterogenous consequences on production costs, depending on the livestock system and production area. The quality-based strategy also requires an evaluation of its impact on prices and ultimately on final demand for bovine meat. If the latter is declining "intrinsically" (i.e. without public intervention or supply-side strategy), then the increase in quality may worsen the decrease in demand of flexitarian consumers (because of higher prices). Moreover, the decrease in demand may be exacerbated if, on top of increased price due to higher quality of beef, public policies are introduced (e.g. tax on beef, regulations, see below). Finally, the size of the remaining low-quality market of domestic bovine meat matters because, if significant, it may reduce incentives for producers to increase quality, as well as the development of a market of exports.

The producer trade-off between domestic and export markets: adapting to diminishing domestic demand and improving competitiveness on international markets

Beef supply may also be adjusted to changes in demand, for the same beef quality, by increasing competitiveness on international markets. By lowering production and other costs (marketing, etc.) and hence market prices, producers may expect to soften the decrease in beef consumption on domestic markets and improve their competitive position on export markets. According to Searchinger et al. (2019), based on simulations using the GlobAgri agricultural market and trade model, a decrease in ruminant meat consumption would still allow cattle farmers with sufficient business opportunities. This is because a decline in demand for red meat on some domestic markets would be partly compensated by a world demand that is expected to rise by 32% between 2010 and 2050.

More competitiveness requires a lower marginal cost, more reactivity to local and external demands, better marketing strategies and innovation in production practices. It also implies a lower cost of cereals and animal feed and a more efficient use of production inputs. Herrero et al. (2013) show that feed efficiency is a key driver of productivity in livestock systems (including cattle, pigs and poultry), whose output depends on a mixed crop–livestock combination in most developed and developing countries. The change in the supply curve (hence, the marginal cost of production) is associated with a move from increasing, constant or decreasing returns to scale, depending on whether marginal cost is below, equal to or above average cost. A decrease in local (domestic) meat consumption might entail a more important role for international trade, through meat exports to countries that did not experience such decrease. Therefore, it is also possible to adopt an export strategy, which probably requires even more competitiveness than on domestic markets and also vulnerability to trade policies from importing countries and to animal health crises. The expected outcome of a competitiveness-based strategy depends on the relative sensitivity of demand and supply to changes in price (i.e. price elasticity of demand and supply). In the standard microeconomic framework, the demand curve would shift downward by a parallel amount, and if the supply curve remains identical, the new equilibrium price is necessarily lower, all else being equal.

To qualify the potential for French farmers to export beef on international markets, when internal demand decreases, it is important to have a look at the demand for meat worldwide. According to Tukker et al. (2011), the European meat production sector will be able to compensate for losses on the domestic meat market (following a decrease in meat demand), by increasing its exports. This result is obtained by assuming that production technologies, protein and energy intake are constant. In a more recent study, the FAO has a less optimistic vision of future export prospects for European countries, however. According to its agricultural outlook 2018–2017 (FAO 2018), developed countries are expected to account for about half of meat exports by 2027, and strong competition from North and South America will prevent the European Union from benefitting fully from export opportunities. Expected growth in income in developing countries will indeed lead both to an increase in global meat demand and to a diversification in the source of animal-based proteins. The FAO projections over the period 2018–2027 point to a lower growth rate for poultry and pig meat and an increase in the demand for more costly animal protein, namely ruminant meat (beef, sheep). In response to higher demand, meat production is projected to increase by 15% over the period, with nominal prices at around US$4000 per tcwe.

France AgriMer (2018a) proposes an exhaustive analysis of export markets for French beef, including a comparison with other exporting countries in terms of cost. For example, in 2013, the average export price for French beef was 431 euros per 100 kg of carcass weight, compared with 287 euros for Australia, 332 euros for the USA, 435 euros for Italy and 431 euros for Germany. Australia and Argentina are remaining major producers of beef and should expand their production further, but beef production from China is expected to reach the same level as the European Union in a few years. Major beef exporters outside the European Union include Australia, Brazil, India, the USA and New Zealand.

The challenge for French agriculture is to succeed to maintain its share of international meat markets by promoting quality meat exports, while avoiding imports from

livestock production systems that would not satisfy similar sanitary and environmental standards. Negotiations between the European Union and the World Trade Organization (WTO) are often made difficult because of different visions of agriculture, as in the Beef Hormone dispute. The European vision of agriculture is also reflected in bilateral trade negotiations, such as Association Agreements with non-OECD countries, or with Canada and the USA. The success of the current negotiations with the latter countries is conditioned on the willingness of European countries to open their markets to American imports, in exchange of the protection of European geographical indicators with third countries. Political uncertainty is another factor to consider towards a conclusion of trade negotiations such as the Transatlantic Trade and Investment Partnership (Tafta). It is clear that opportunities for French quality beef exporters are, at least partly, conditioned upon the success of such negotiations.

Although a decrease in domestic demand provides additional opportunities for exports, provided that competitiveness of domestic bovine production is sufficient, the indirect consequences of reduced production costs need to be addressed. Investment in large-scale livestock farms is a way to exploit economies of scale by reducing marginal production costs. However, concerns about increased environmental impacts and opposition from local communities (low social acceptance) may limit the scope of such option to improve productivity. Additionally, lower production costs and the development of export markets may provide livestock producers with incentives to downgrade the quality of their own production, if export market conditions are favourable. A scenario where "low quality drives out good quality", with gains in productivity through investments in large-scale production facilities, is not likely to be sustainable at the national level. It is necessary to identify livestock systems and production areas that may benefit from this scenario, based on an analysis of respective gains and losses for livestock producers and on their contribution on export markets.

Policy instruments to promote adaptation of beef supply

We consider here policies that need to be designed to accompany agricultural producers in a context of decreasing meat consumption, including producer support policies and payment schemes for environmental services (Dumont and Dupraz 2016). In addition, private strategies mentioned above can be accompanied by public regulation, research and development, training and communication policies. In designed public policies targeted at the supply side, several issues need to be addressed. First, how can income reduction of cattle farmers be compensated by a payment from a public policy, e.g. the European Common Agricultural Policy? Second, it is important to compare consumer welfare gains (due to change in diets) with producers' profit loss, for each policy package, in order to determine the most cost-effective policy. The expected performance of public policies aiming at transitions in production systems depends on the potential for farmers to adopt production practices with a valuation of better practices (animal welfare, reduction of environmental impacts), given existing agricultural policy (Common Agricultural Policy, etc.). It also depends on the trends in diets and on the beef market outlook. The whole industry involving bovine meat must not be overlooked (feed industry, processing, veterinary services, etc.), as the supply-side agents include more than primary producers (stock breeders), who may require support policies as well.

Public intervention may be considered if incentives for enhanced quality are too low, due to decreased demand and the existence of a low-quality export market. A first possible policy is to impose production constraints, which would result in a fraction of bovine meat production being eliminated, with consequences on the environment through land use changes and transition in livestock systems. A second policy instrument is a subsidy on production cost of cattle farmers, which can take the form of an earmarked tax on bovine meat consumption, to subsidize producers towards quality production systems. Such policy would compensate producers' efforts towards quality enhancement and limit the price increases due to increased meat quality. Caution must be paid however, regarding compliance with international trade regulations and the need to avoid provision of incentives towards low-quality beef production for export markets. The tax policy has therefore to target domestic markets only.

Policies may also involve non-market goods and services provided by higher quality beef and associated with better environmental conservation, through, e.g. payment for environmental services (see Dumont and Dupraz 2016) on legal and regulatory conditions for implementing payment for environmental services from livestock in France). In the foresight exercise on the future of the beef sector proposed by FranceAgriMer (2018b), payment for environmental services provided by pasture may be associated with carbon sequestration, water purification, biodiversity conservation, aesthetic dimensions, pollination, flood and fire risk reduction, erosion control and groundwater recharge. Regarding the environmental service of GHG emissions mitigation obtained from technology innovations, Bryngelsson et al. (2016) estimate the potential reduction in food-related GHG emissions in Sweden. They show that emissions of methane and nitrous oxide could be cut by around 50% while improving productivity. This result is however conditioned on a large reduction in beef meat consumption, as well as substantial advances in production technology. In the USA, Hinrichs and Welsh (2003) compare the relative ability of animal sectors to use an intensive pasture system as a sustainable livestock alternative. They show that some cow–calf beef farms are more associated with sustainable agricultural practices than other, more strongly integrated sectors. Havlik et al. (2014) analyse policies jointly targeting transitions in livestock systems and climate change mitigation. They conclude that policies fostering a combination of productivity improvement in livestock production with a climate policy targeting land-use change are likely to be the most efficient to reach climate and food security objectives.

To conclude this section on supply side considerations, strategies involving quantity–quality and domestic export market trade-offs may be considered with or without public intervention to foster of accompany transitions in diets and livestock systems. However, enhanced competitiveness on domestic and international markets may be limited by the low social acceptance for options based on large-scale livestock farms with possibly increased environmental impacts. A strategy of increased average quality seems more promising, with the potential for higher price mark ups for farmers, and even the possibility of payment for environmental services associated with cattle livestock. Finally, for both strategies, an evaluation of the impact of increased average quality on consumer welfare and farmers' profit is necessary, based on consumer preferences and willingness-to-pay, production costs and marketing strategies. Necessary data to conduct such evaluation include an indicator of "quality" in terms, e.g. of environmental indicators (footprints) of conventional and high-quality meat production

processes, price elasticities of beef demand (including substitution elasticities with vegetable products), production cost and output supply technology and non-market valuation of environmental benefits of quality beef production.

A simulation experiment

In the previous sections, we aimed at identifying the main drivers and variables necessary to evaluate the economic and environmental impacts of changes in the demand for beef, induced by changes in consumer preferences or by consumer-oriented policies. Such identified drivers include the increased consumer awareness about environmental issues, consumers' WTPs and trade-off between red meat and meat substitutes, the consumer and producer "quantity/quality" trade-off on the domestic market and the producer trade-off between the higher-quality domestic market and the lower-quality export market.

A simple model of demand–supply interaction

To analyse the interactions between these different dimensions, and to assess their potential effects on market equilibrium, we consider here a simple model for red meat (beef). On the demand side, we consider a representative domestic consumer who buys a quantity q_m of beef and a quantity q_v of a substitute product, assumed to be more environment-friendly (for instance, plant-based proteins). The total quantity $C = q_m + q_v$ is supposed to be constant and corresponds to the consumer's total calories or protein needs. The consumer surplus is as follows:

$$S_C = [\beta_m - I(1-k_m)]\log(q_m) + \beta_v \log(C-q_m) - p_m(1+\tau)q_m - p_v(C-q_m). \quad (1)$$

In this expression, β_m and β_v are the willingness-to-pay for one unit of each product and represent consumer's preferences (taste, cultural value…) for the meat product and the substitute product respectively. p_m and p_v denote market prices of the two products respectively; k_m is the environmental quality of the red meat product; and $(1 - k_m)$ is the environmental externality induced by the production of one unit of red meat, given its environmental quality k_m. I is the weight given by the consumer to the environmental externality and represents the consumer's awareness about the environmental impact of red meat consumption; τ is the ad valorem tax rate applied on the domestic red meat product. We assume that the consumer maximizes her surplus with respect to the quantity of red meat q_m^* she wants to buy. The demand for the substitute product is simply obtained by $q_v = C - q_m^*$, given the exogenous parameters β_v and p_v.

Expression (1) allows for capturing important drivers of meat demand. For instance, an increase in I corresponds to an increase in consumer's awareness about the relationship between red meat and the environment, which can be spontaneous or induced by environmental labelling. Given I, an increase in the environmental product quality k_m increases consumer surplus. Variations in β_m and β_v can express changes in consumer's

preferences that could be induced by information campaigns or food industry innovations. It is important at this stage to discuss some of our simplifying assumptions. First, we consider a representative consumer, whereas we have previously stressed the existence of consumers' heterogeneity. Our assumption means that, with the model specification, we cannot capture the effects of market segmentation within the domestic market. We assume that the consumer chooses demand level q_m^*, given C and the characteristics of the meat substitute market (and then q_v is a consequence of the choice of q_m^*), rather than deciding simultaneously the quantities q_m and q_v, which would be more realistic. Second, if demand for the meat substitute changes, then price p_v would likely also change. We do not integrate here this price reaction on the meat substitute market, as p_v is exogenous. Third, regarding the tax on red meat, we only consider an ad valorem tax instead of an excise tax, whose rate would depend on the meat product quality and could have a bigger impact on demand.

Let us now turn to the supply side. A representative red meat producer has to select the quantity to sell on both markets for red meat, given a total production capacity K: a domestic market that corresponds to the domestic consumer described above and an export market. On the latter, market price p_E and production cost c_E are assumed exogenous, and the producer is price taker. The production cost of the red meat product ck_m^2 is assumed to be convex in the quality level k_m chosen by the producer. The producer profit is given by the following:

$$\pi_m = q_m\left[p_m - ck_m^2\right] + (\mathrm{K} - q_m)[p_E - c_E]. \tag{2}$$

In this setting, it is possible to deal with the quantity/quality trade-off on the domestic market and with the trade-off between domestic and export markets. However, important simplifications and assumptions must be noted. First, we do not consider any product differentiation on the domestic market: k_m must then be considered an index of the average environmental quality of the domestic market. Second, we do not consider any quality decision on the export market and we simply assume that the product quality on the export market is fixed and normalized to $k_E = 0$. Hence, export cost is exogenous in our modelling framework, while the cost of the domestic product is adjusted on quality (which is assumed predetermined on the export market). It would be possible to consider that both export and domestic products have the same quality level, but we do not make the parameter for export cost c_E (depending on quality k_E) vary, as the equilibrium level k_E does not depend on the domestic (French) market.

Third, we assume that the export market price is exogenous, which implies that the producer is only price taker on this market. Fourth, we assume that the producer is a monopolist on the domestic market, and we do not take into account the vertical relationships between stakeholders in the meat supply chain and their potential impact on price transmission and quality choices. Finally, the production capacity K is assumed exogenous, whereas in practice, the producer could also decide on the size of this capacity.

To characterize the market equilibrium, we assume that the producer first chooses the quality level k_m^* of the red meat product, as it is a long-term decision. This decision

is made by anticipating the results of the interaction between demand and supply, determined by the maximization of consumer surplus and producer profit respectively.

The consumer demand for the red meat product is a solution to a quadratic equation allowing for two distinct roots:

$$q_m^*(p_m, k_m) = \underset{q_m}{\text{Arg max}}\, S_c = \frac{1}{2(p_m - p_v)}\left[\beta_m - I(1-k_m) + \beta_v + C(p_m - p_v) \pm \sqrt{\Delta}\right],$$

where:

$$\Delta = \beta_v^2 + 2\beta_v[\beta_m - I(1-k_m) + C(p_m - p_v)] + [\beta_m - I(1-k_m)]^2 + [C(p_m - p_v)]^2 - 2C\{[\beta_m - I(1-k_m)]\,(p_m - p_v)\}.$$

In practice, consumer demand corresponds to the smallest positive real-valued solution given above.

We determine the price at equilibrium by maximizing the producer's profit with respect to p_m and by integrating the resulting consumer demand for q_m^* in the expression of the producer profit:

$$p_m^*(k_m) = \underset{p_m}{\text{Arg max}}\, \pi_m. \tag{3}$$

The optimal quality k_m^* may be obtained by maximizing producer profit with respect to k_m, given $q_m^*(k_m)$ and $p_m^*(k_m)$. As it is not possible to derive a closed form solution from our model specification, we solve Eq. (3) numerically to determine supply price $p_m^*(k_m)$ and optimal quality k_m^*. Based on this, it is finally possible to calculate consumer surplus and producer profit at the equilibrium, as well as the environmental externality induced by the production of the domestic and export products ($E = q_m^*(1-k_m^*) + K - q_m^*$) and the total consumer expenditures ($S = q_m^* p_m^* + (C - q_m^*)p_v$). Note that, with our specification, a decrease in E implies an improvement of the state of the environment.

Figure 1 displays producer profit and consumer surplus for a grid of values of k_m, and Fig. 2 represents producer profit for different values of consumer's awareness I. It turns out that:

- Below the optimal quality k_m^* chosen by the producer, her profit increases when k_m increases because the red meat price and quantity both increase, which compensates the increase in the production cost. Above k_m^*, the profit decreases, because the decrease in $q_m^*(k_m)$ and the increase in production cost ck_m^2 are not compensated by the increase in $p_m^*(k_m)$.
- The optimal quality k_m^* chosen by the producer is lower than the quality level that maximizes the consumer's surplus.
- The optimal quality k_m^* chosen by the producer increases when the consumer's awareness increases.

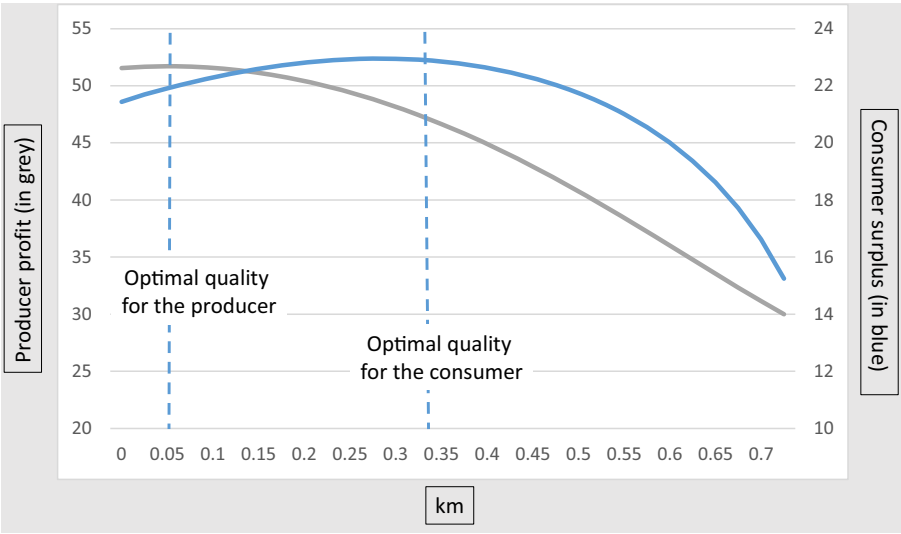

Fig. 1 Producer profit and consumer surplus according to the environmental quality k_m

Simulation results

Table 1 displays the results of numerical simulations and the optimal values k_m^*, p_m^* and q_m^* for different values of the main parameters. In this model setting, an increase in the consumer's awareness I leads to a table decrease in the consumer's surplus,

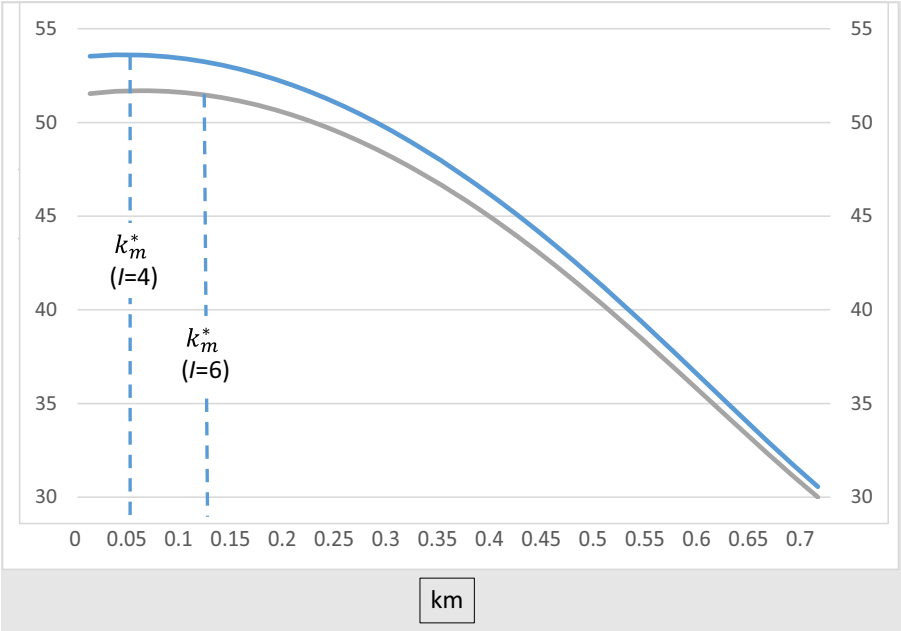

Fig. 2 Producer profit and optimal quality according to consumer awareness (I)

Table 1 Model outcomes depending on parameter values

	c	k	I	c	β_m	β_v	c_E	p_E	p_v	τ	k_m*	p_m*	q_m*	CS	Profit	Env.	Exp.
Baseline	25	25	4	4	15	15	1.5	2	4	0.0	0.035	3.31	14.64	99.03	53.61	24.49	89.93
Change I	25	25	6	4	15	15	1.5	2	4	0.0	0.051	3.19	14.63	95.92	51.70	24.25	88.13
Change c	25	25	4	0.5	15	15	1.5	2	4	0.0	0.274	3.39	14.59	100.50	54.09	21.00	91.06
Change β_m	25	25	4	4	10	15	1.5	2	4	0.0	0.035	2.97	14.64	90.61	48.61	24.49	84.93
Change β_v	25	25	4	4	15	20	1.5	2	4	0.0	0.038	3.18	13.04	112.92	47.41	24.50	89.36
Change c_E	25	25	4	4	15	15	0.9	2	4	0.0	0.037	3.50	13.62	96.39	60.12	24.50	93.20
Change τ	25	25	4	4	15	15	1.5	2	4	0.20	0.028	2.91	13.66	96.43	45.36	24.61	93.05

which leads the producer to readjust the optimal quality. We then observe a quantity/quality substitution by the consumer on the red meat market, as the optimal quantity of red meat decreases while the optimal quality increases. This scenario is beneficial for the environment, but detrimental for both consumer surplus and producer profit. Note however that the substitution between the red meat product and the substitute product leads to a decrease in consumer expenditures S. A decrease in the production cost of the quality k_m is also beneficial for the environment, but without inducing a decrease in consumer surplus and producer profit. Production cost c is the only variable that has the desired properties on the three dimensions (consumer welfare, producer profit and the environment).

All other parameters have a detrimental effect on the environment. Compared with the baseline situation, an increase in the willingness-to-pay β_v for the substitute product leads not only to an increase in product quality but also to a significant reduction in the quantity q_m^* sold on the domestic market. This in turn leads to an increase in the size of the export market, whose environmental quality is supposed to be much lower.[2] A decrease in production cost on the export market, c_E, increases producer profit, reduces consumer surplus and has a negative impact on the environment. The ad valorem tax, τ, leads the producer to reduce production costs, decrease the optimal quality k_m^* and increase the quantity sold on the export market. The consequence is, once again, a negative impact on the environment.[3]

Our initial question was to determine whether a "win–win scenario" is possible in the aftermath of decreased red meat demand on the domestic market. In other words, we want to determine under which conditions a reduction of red meat consumption, induced by an increased consumer's awareness about the environmental impact of red meat, might be such that producer profit and consumer surplus are at least as high as in the initial situation. In Table 2, we compare several scenarios with the aim to determine the effects of the different parameters of the model on the market equilibrium, in a context of changes in the consumer demand and the possibility to restore a win–win situation compatible with an environmental gain. We start with an initial baseline, and include successive modifications of the parameters, related to consumer's awareness (scenario 1), production cost on the domestic market (scenario 2), willingness-to-pay for the red meat substitute and production cost on the export market (scenario 3) and the tax on red meat (scenario 4).

Compared with the baseline, as mentioned above, the increase in consumer's awareness (scenario 1) induces an environmental benefit, but both consumer and producer lose in terms of surplus and profit respectively: it is a "lose–lose" scenario. The decrease in the production cost of the domestic product (scenario 2) favours a quality increase that generates an environmental gain, restores the consumer surplus, but is not sufficient to restore producer profit (the price increase does not compensate for the decrease in quantity): it is a "win–lose" scenario. To obtain a win–win scenario at this stage, it is necessary to simultaneously decrease the production cost on the export market, in order to increase the producer profit, and to increase the consumer willingness-to-pay for the meat substitute, in order to not to decrease too much the

[2] Note that an increase in β_v could induce a reaction in price leading to an increase of p_v. This effect is not taken into account here.

[3] Recall that an increase in E represents a deteriorated state of the environment.

Table 2 Comparison of scenarios

	C	K	I	c	β_m	β_v	c_E	p_E	p_v	τ	k_m*	p_m*	q_m*	CS	Profit	Env.	Exp.
Baseline	25	25	4	4	15	15	1.5	2	4	0.0	0.035	3.31	14.64	99.03	53.61	24.49	89.93
Scenario 1	25	25	6	4	15	15	1.5	2	4	0.0	0.051	3.19	14.63	95.92	51.70	24.25	88.13
Scenario 2	25	25	6	0.5	15	15	1.5	2	4	0.0	0.413	3.36	14.52	99.26	52.78	19.01	90.69
Scenario 3	25	25	6	0.5	15	20	0.9	2	4	0.0	0.508	3.55	11.57	110.62	54.38	19.13	94.82
Scenario 4	25	25	6	0.5	15	20	0.9	2	4	0.20	0.436	3.23	9.78	106.18	47.38	20.74	98.76

consumer surplus (scenario 3). However, this win–win solution is obtained at the expense of a worse environmental impact. The implementation of an ad valorem tax (scenario 4) has negative effects on optimal quality, consumer surplus, producer profit and the environment. However, it is still a win–win scenario. Overall, from the baseline to scenario 3, the optimal quantity q_m^* decreases while the optimal quality k_m^* increases; the size of the export market increases, but the quality increase in k_m^* on the domestic market offsets the negative environmental impact of the increased size of the low-quality export market. Eventually, the tax reduces both the optimal quantity and quality, leading to a smaller environmental benefit.

To provide a full economic assessment of these different scenarios, it would be necessary to include the economic value of the environmental gains and the public costs (labelling policy and information campaigns to modify β_v or I; interventions to favour productivity gains or subsidies to reduce production costs) and benefits (tax revenues) associated with each scenario. We have also identified important limitations, as we did not take into account, for instance, consumers' heterogeneity (we considered an average consumer instead), the complexity of the red meat supply chain (atomicity of red meat producers, vertical relationships between producers, processors and retailers) or the existence of a low-quality domestic market. These issues are beyond the scope of this paper and would have to be included in further research.

Despite these limitations, it is interesting to note that in the context of an increased consumer awareness about the environmental impact of red meat, the substitution between quality and quantity may be implemented by both the producer and the consumer. Moreover, under some conditions, they both contribute to an improvement of the overall environmental state. A win–win scenario can only arise by modifying simultaneously several parameters, both on the demand and the supply side. In addition, the best solutions in terms of environmental impact are not necessarily those that have the greatest effects in reducing the low-quality export market. In some cases, the increase in the environmental quality on the domestic market may compensate the negative effect on the environment due to an increase in the size of the low-quality export market.

Obviously, in our model setting, if consumers are not fully aware of the environmental impact of meat consumption ($I = 0$), producers have no incentive to increase the meat product quality ($k_m^* = 0$). The consequence is that, with regard to the environment, the two are complementary: the greater the I, the larger the environmental gain associated with an incremental increase in k_m. This means that combining environmental labelling in order to increase I (for instance, on the basis of the carbon footprint of beef depending on production practices) and subsidies to favour an increase in environmental product quality (i.e. a decrease in c) may be a relevant policy mix that could influence in a consistent way producer and consumer decisions. However, this policy mix may not be sufficient to compensate the welfare loss induced by the increased consumer awareness about environmental impact of meat production. It is for this reason that other instruments, focused on the substitute and the export markets, may be needed in order to restore the producer profit and to reach a win–win situation. However, because such a scenario is costly for the policy maker, a tax policy on red meat may be preferred, as it would generate fiscal revenues, even though it decreases environmental gains. A full benefit–cost assessment would be needed to confirm this statement and to compare these scenarios with the results of a social welfare maximization.

Finally, we did not consider the reduction of the production capacity K in the simulations. It is clear that in this model, a reduction in K, which could be imposed by a public authority, would reduce automatically the environmental impact and reduce the product surplus, without modifying the quality level selected by the producer. This issue is more complex however, as it also depends on the nature of the competition on the export markets and on the environmental quality of production systems of international competitors. This issue is left for future research.

Concluding remarks

This paper has made a case for a scenario where changes in consumer preferences towards less bovine meat in diets are accompanied by a transition in livestock production systems towards more quality beef. The credibility of this win–win scenario is examined in the case of a developed country (France), and ingredients for a welfare analysis that would integrate demand-side and supply-oriented dimensions are discussed.

Our conclusion is that a new demand–supply equilibrium may be reached, with a lower beef consumption per head, but of a higher average quality on the domestic market, under a detailed set of conditions. In the aftermath of an increased consumer awareness about the relationships between red meat and the environment, environmental benefits can be obtained from public interventions allowing for a decrease in the production cost of higher quality products. Such interventions are beneficial on the three dimensions (consumer welfare, producer profit and the environment). But the win–win scenario is not guaranteed, as they may not be sufficient to restore producers' profits at the initial value (before the decrease in the red meat demand).

If the social planner's choice is to keep producer profit at least to the baseline level, then other levers of action must be used. A decrease in production cost on the export market (in order to increase producer profit), while increasing the consumer willingness-to-pay for the meat substitute (in order to not decrease too much the consumer surplus), can complement a subsidy on the higher-quality production on the domestic red meat market. Our results show that well-designed cost-reduction and marketing strategies, possibly involving public policies to accompany consumers and producers in their transition, are necessary to simultaneously target demand and supply sides.

Several questions remain however to be addressed. Even if a country like France potentially satisfies conditions to achieve a successful transition in consumption and production in parallel under the win–win scenario, the resulting environmental outcome remains to be evaluated. Non-market valuation methods would be required to assess and construct an aggregate indicator of the environmental impact of the scenario. This requires collection of more and better data on food systems and better designed models to explore consumer deviations from "nutritionally optimized" diets and their environmental consequences. Moreover, a significant change in diets towards less beef would likely affect the beef sector in a more complex way than would be predicted with a model with representative consumer and producer. Hence, an extension of the simplified demand–supply model for beef towards heterogeneous populations of consumer and cattle farmers would be interesting to consider. Such extension may be used to

explore more realistic representations of consumer response to changes in beef price, as well as price and quality strategies of producers, depending on sociodemographic backgrounds and local production conditions. In particular, the structure of the beef industry, including the market power of agri-food processing and retail industries and the industrial organization within the industry, may be made explicit in a more realistic simulation model, to relax the assumption of a representative producer. For example, introducing vertical differentiation on the domestic market would allow us to consider the case of low-quality (and low-price) imports of beef as a strategic move of exporters to France, in response to an increased average quality of beef from domestic producers. This is left for future research.

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