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Title

Integrating epidemiological and economic models to identify the cost of food-born diseases

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Abstract

Despite food technology advancements, food safety policies, and alert systems, food borne diseases are still a relevant concern for consumers and public health authorities, with great impacts on the economy and society. The economic evaluation of food-borne diseases is needed to design appropriate interventions. The first step of this process is the identification of the potential cost of the disease , which requires a conceptual framework based on system thinking and inter/trans-disciplinarity. This paper proposes a simple method for cost identification of food-borne diseases, accessible to researchers and practitioners who are not specialist in economics. The method is based on the assumption that epidemiology and economics should integrate their approaches to analyse the disease consequences in a wider socio-economic perspective according to a systems view. To this aim, the authors first focus on the links between epidemiological and economic models, i.e. how food-born disease outcomes impact on efficient use of economic resources . Then they show how simple economic models, such as the food-supply chain, can be used to identify a wide range of consequences determined by the food-born diseases across economic sectors and society.

Keywords: cost, foodborne diseases, food supply chain, system thinking, interdisciplinarity,

Highlights (3-5 bullets, 85 caratteri/bullet)

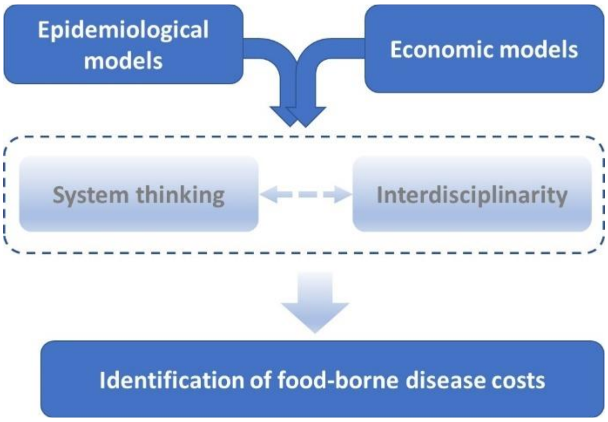
- Identifying food-born diseases cost needs system thinking and interdisciplinarity
- Epidemic and economic models can be integrated for cost identification
- Food supply chain model can guide to identify cost across sectors and the society

Abbreviations

BOD: burden of disease
CBA: cost benefit analysis
COI: cost of illness
COST: Cooperation for Science and Technology
DALY: disability adjusted life years
Echin. Gran.: Echinococcus Granulosus
EFSA: European Food Safety Agency
EFTEC: Economics for the Environment
EU: European Union
FAO: Food and Agriculture Organization
FBD(s): foodborne disease(s)

FBP(s): foodborne parasites
FSCh(s): food supply chain(s)
NEOH: Network for the Evaluation of One Health
OECD: Organization Européenne pour la Coopération et le Development
OH: One Health
OIE: (Office Internationale des Epizozies) World Organization for Animal Health
QALY: quality adjusted life years
WHO: World Health Organizations
WTP: willingness to pay

Graphical abstract



1. Introduction

Food borne diseases (FBDs) include a wide range of diseases which hit human beings in different ways and through different transmission mechanisms (Dorny et al., 2009; EFSA, 2018). They are spread worldwide taking lower or greater importance depending on the specific contexts (Todd 1988; Van DeVenter, 2000, OECD-WHO, 2003; Kaferstein et al., 2007; WHO 2015; Seimenis and Battelli, 2018;). The knowledge of FBD epidemic models and associated costs are key information to conceive health policy strategies to limit effects on population and society (Dewleesschauwuer et al., 2017). Due to the complexity of transmission mechanisms, there are still gaps in the specification of FBDs epidemic models and the quantification of cases and health consequences (Flint et al., 2005; Robertson et al., 2018), and this undermine the evaluation. A large stream of scientific production on FBDs' effects is dedicated to the calculation of the burden of diseases (BOD) which leans on the concept of health losses, usually measured through disability adjusted or quality adjusted life years (respectively DALY and QALY). These are non-monetary measures at individual level that can be aggregated at higher levels (e.g. population layers, social categories, geographical context) with relevant advantages in epidemic studies (WHO, 2015). This method reflects a sectoral approach to the evaluation because it focuses health consequences and do not consider the complexity of effects determined by FBDs in the larger context of the economy and the society. Secondly, from an economic perspective, BOD monetization puts some conceptual and material problems which monetary approaches, such cost of illness (COI), willingness to pay (WTP) and cost benefit analysis (CBA) try to overcome. WTP bypasses the problem of disability monetization by assessing individual propensity to investing money to avoid adverse health outcomes (Roberts, 2007; EFTEC, 2017). COI includes both direct costs (those directly born by public health system and private citizens to implement disease therapies) and indirect costs (e.g. the consequences of the BOD on the economic and emotional status of the patient and the loss of productivity) (Scharff, 2012, Changik, 2014). Social CBA focuses an even wide range of situations which suffer directly and indirectly the consequences of FBDs, i.e. not only the patients and the loss of productivity but also the cost born by the activities linked to the food vehiculating the disease along the food production system (Robertson et al., 2018; Suijkerbuijk et al., 2017). These approaches go beyond the sectoral limitation of the mere disability quantification and extend the evaluation across sectors (health care system, production system). At empirical level, costs arising from FBDs are manifold. They are often categorized according to classification criteria (Carabin et al., 2005; Gadiel 2010; Jansen et al., 2018), extensive meta-analysis of the scientific literature also provides empirical information about the types of cost that researchers include in their evaluation (Buzby and Roberts, 2009; Belaya et al.; 2012, McLinden et al., 2014;), while some works focus evaluation domain usually not considered in the prevailing evaluation literature such transnational perspective, cost of product recall for distributors, sales reduction following food alert, cost of compliance, etc. (OECD-WHO, 2003; Kaferstein, 2007; Ribera et al., 2012, Hussain, 2013).

It's not among the aims of this paper to review the evaluation methods, their pros and cons or their implementation limits, but to first stress that most evaluation studies pay poor attention to how (i.e. according to what conceptual framework) costs are identified or listed. Cost identification is a preliminary step in the evaluation process (Drummond et al., 2015). It logically foreruns cost quantification, of course the most important and expected result of economic evaluation, capturing the greatest attention at scientific and political level. Several reasons stand for focusing cost identification and the way it is performed. Zoonosis determine multiple effects which expand from the individuals to the society according to trans-sectoral pathways. Managing this complexity requires specific conceptual approaches which can capture the whole range of effects occurring in the society, as much as the current scientific knowledge allows for. Reasoning in terms of complexity requires in turn that inter- and trans-disciplinary work-routines are developed among the different actors (e.g. institutions, researchers, health practitioners and administrators, social bodies). This approach can lead to the creation of a common expanded knowledge which can be shared and criticised to increase the effectiveness of the research, the social awareness of the consequences, and finally support rational decision-making process.

The EU funded COST Action "Network for the Evaluation of One Health" (NEOH, COST Action TD 1404) developed a method for the evaluation of One Health initiatives during its mandate (2014-2018) (http://neoh.onehealthglobal.net/). NEOH approach focuses in particular the evaluation of One Health initiatives in view of assessing the effectiveness of OH approach in comparison with current traditional approaches to health. It goes through four main elements: (i) defining and describing the OH initiative and its context (i.e., the system, its boundaries, and the OH initiative as a subsystem); (ii) assessing expected outcomes based on the theory of change (TOC) of the initiative, and collecting unexpected outcomes emerging in the context of the initiative; (iii) assessing the "OH-ness", i.e., the implementation of operations and infrastructure contributing to the OH initiative; (iv) comparing the degree of "OH-ness" and the outcomes produced (Rüegg et al, 2018). Beside the specific aim mentioned above, NEOH approach combines in a coherent framework a set of conceptual tools (namely system approach, inter- and transdisciplinary, theory of change) which allow tackling complexity of health problems in their context. These tools can be applied to build up a framework for the identification of FBDs cost which reflects the complexity of FBDs effects across the society, according a cross-sectoral systemic view and in line with OH concept.

The aim of this paper is to provide elements and suggestions about the possibility to fill the gap, which apparently exists in the current literature, concerning the methods to identify FBDs costs. In this paper we focus in particular the role of system thinking and interdisciplinarity in the identification of disease effects of FBDs, providing a simple way to identify disease consequences and costs. A key step on this way is to show how different disciplinary domains, namely epidemiology and economics, can work together by integrating epidemic models and economic models. First, we will briefly recall the basic concepts forming the conceptual background (§ 2); then we will focus on how they can work together in view of the objective of this paper (§ 3); finally we will draw conclusions and consideration about the utility of the effectiveness of the proposed method.

2. Materials and methods

Given the aim of this paper, materials and methods are basically of conceptual nature and they concern system thinking and inter-/trans-disciplinarity, and the meaning of epidemic and economic models, focusing in particular the food supply chain (FSCh) model.

2.1. System thinking and inter-/trans-disciplinarity

System thinking and inter-disciplinarity are increasingly used to solve complex problems (including health related ones) where traditional approaches, based on linear causation, mono- or multi-disciplinarity, fail or show limits in problem understanding and problem solving. Systems thinking covers a wide range of concepts and theories (Hofkirchner and Schafranek, 2011). Adopting a system view or approach implies that we examine a problem as part of a wider context, where it represents an element connected with other elements by complex, dynamic relationships. At the operational level, this approach is increasingly applied to health and related issues and policies (de Savigny and Taghreed, 2009; Anderson, 2016; Hitziger et al, 2018;). According to Meadows (2008) a system is "*A set of elements or parts that is coherently organized and interconnected in a pattern or structure that produces a characteristic set of behaviors, often classified as its function or purpose.*". The definition suggests that a system can be articulated in units of different nature, connected with each other by different kind of interactions (direct and indirect causation, feedbacks or loops, of different sign and intensity). Partitions (sub-systems) may appear within a wider system, showing a relative homogeneity or similarity in relation to the effect they produce or the role they play in the general framework. The identification of system limits is a crucial aspect for system thinking to be effective, avoiding undue expansion of the system. Limits may arise from objective scientific criteria or practical consideration thus they may subjective as they depend from the observer's interpretation of the reality, but should not be considered arbitrary.

Inter- and trans-disciplinarity are functional to system thinking, as system complexity cross the boundaries of scientific disciplines, sectors or institutional competencies. Differently from mono- and even multi-disciplinarity, interdisciplinarity "*involves the integration of perspectives, concepts, theories, and methods to address a common challenge*" (Rüegg et al., 2018), while trans-displinarity goes beyond the boundaries of academic knowledge by involving institutions, communities and social parties in the building up of new knowledge. Implementing inter-/trans-disciplinarity needs participative practices and teamwork organization as well as specific methods to elicit and synthesize across multiple point of views. These are quantitative and qualitative methods well rooted in team or project management and decision support (i.e. stakeholder analysis, multicriteria analysis, Delphi technique, and similar). Also, simple tools can be conceived to ease interdisciplinary team working in the day-by-day routine (Aragrande and Canali, 2015).

2.2. Epidemiological models

According to Hethcote (1989) "*an epidemiological model uses a microscopic description (the role of an infectious individual) to predict the macroscopic behavior of disease spread through a population"*. According to Keeling and Ames (2007) mainstream disease models basically "*describes the number of individuals (or proportion of the population) that are susceptible to, infected with and recovered from a particular diseases*", making reference to the "*foundations of almost all of mathematical epidemiology: the susceptible-infectious-recovered (SIR) model.*". Though an equivalent definition doesn't exist on the veterinary side, in this context an epidemiological model has been defined as a "*mathematical and/or logical representations of the epidemiology of disease transmission and its associated processes … among animals, and/or among groups of animals, in time and/or space*" (Willeberg et al, 2011). Because of their quantitative nature, epidemiological models lend to simulation and find their most useful application in the management of health crises and to test the effectiveness of possible intervention strategies (Dubé et al, 2007), given that "*Experiments with infectious disease spread in human populations are often impossible, unethical or expensive*" (Hethcote, 1989). The above-mentioned definitions allow for the assumption that an epidemiological model can be considered a system in itself, where units and subsystem of different nature and dimension show specific behaviours (of biological or social nature) and interact according to complex relationships (transmission mechanisms), determining effects at different levels and in different contexts (e.g. human or animal diseases, the environment, the economic sectors). Often epidemiological models are described graphically to outline complex relationships and effects (Figure 1). This approach is well grounded in epidemiology (Joffe et al, 2012; EFSA, 2018) and in many applications of the systems theory (Anderson and Johnson, 1997; Meadows, 2008;) not only as an alternative to wording but as a tool to ease and improve understanding.

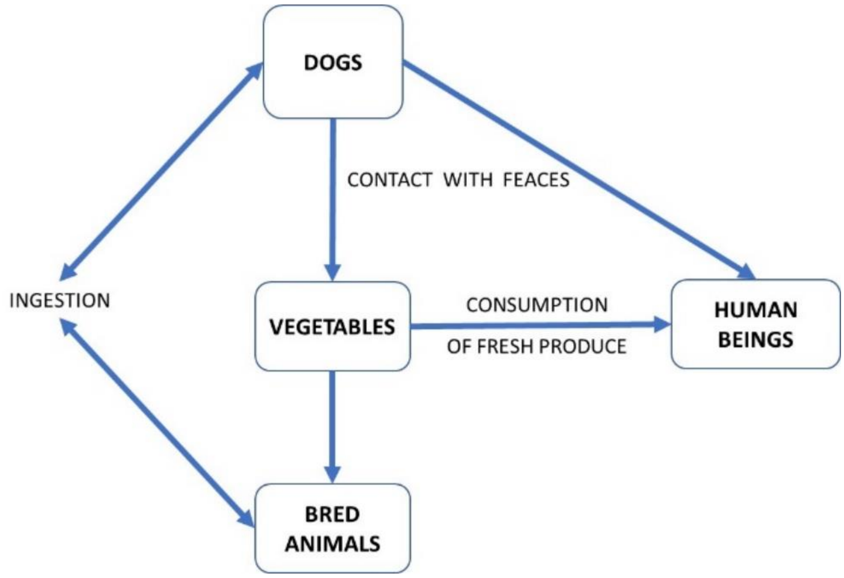


Figure 1 - Elementary epidemiological model of Echinococcus Granulosus
The figure is a simplified and generic representation of the epidemiologic model of Echinococcus Granulosus (*Echin. Gran.*) where the white boxes are the intermediate and final hosts, and the blue lines the ways of transmissions.

2.3. Economic models

An economic model is a conceptual tool to represent economic phenomena, i.e. how relevant economic variables interact to produce economic effects. A cartesian diagram of the market, where demand and supply functions are represented in relation to price and quantity, well represents the basic idea of an economic model. In its simplicity, this model (as well as many others in economics) allows to explain and predict the result of economic behaviour (e.g. consumer and producer behaviour in reaction to price variation) on the basis of the assumption (at the core of the economic science) that resources (i.e. anything can be used to create some kind of utility for the individuals and the society) are scarce. Resource scarcity implies that a rational choice is needed to allocate them among alternative uses to get the maximum utility; and that when a resource is allocated in a use, the utility it could produce in an alternative use is lost (the so-called opportunity cost, which is at the core of the common concept of cost in economics) (Canali et al, 2018). When resources are destroyed or their ability to create utility is limited, resource efficiency (i.e. the amount of utility a resource can create) is lost; this loss is a cost for the individuals and the society. In economic terms, diseases are events which reduces the efficiency of resources (human beings and animals) to some extent. Said in other words, pathologies alter the health status of humans and animals and affect their efficiency in the creation of economic utility, causing welfare losses, or costs, that are the object of the economic evaluations. The same way, human actions to prevent, contain or eliminate diseases also imply the decision about the allocation of limited (usually monetary) resources, determining private and public costs. The economic evaluation assesses the cost of the diseases and supports the decisions making of individuals, businesses and/or public administrations about the health measures to undertake for reducing disease impacts and social costs. Efficiency losses of resources can be assumed as the functional and conceptual link between epidemiology and human and animal health economics (Howe, 1988). A wide list of costs can be identified depending on the type of pathogen, the transmission mechanisms and the social and economic behaviour: e.g. costs of medical and hospital cares, hours of work lost by affected humans and their relatives involved in patient care, costs of veterinary treatment for companion and farm animals and related additional work for farmers, livestock losses and related costs for carcass disposal, losses of values along the food supply chain, for example due to food alert (Aragrande and Canali, 2017), animal welfare losses (Vetter et al., 2014; Gibson and Jackson, 2017), costs of disease monitoring and surveillance. As mentioned above, cost listing is usually made apparently without a conceptual framework that could provide health operators (researchers of different academic domains, health administrators, health institutions) with general guidelines to identify diseases consequences and cost before (or independently) from their quantification and evaluation. While quantification and evaluation require disciplinary and technical competences, the mere identification of consequences would benefit from the close cooperation among different disciplines in a comprehensive inter-disciplinary framework. The identification of the economic consequences of any disease may be operated by integrating the epidemiology of the disease (the epidemiological model) and the economic functions of the impacted entities (the economic model).

Among the many economic models, the food supply chain model (FSCh) may prove effective for the aim of this paper. The FSCh identifies the series of technical steps leading from raw material to product(s) across economic sectors (agriculture, processing, distribution). It’s graphical representation is usually linear but it can include side complementary activities of the production system which develop around a product. More recent applications of the FSCh model in agro-food economics (Malassis and Ghersi, 1996) focus the complex relationships occurring along the food supply chain which determine its structure, functioning and socio-economic performances (i.e. production capacity, competitiveness, distributional effects, job creation, etc.). In this sense a FSCh (Figure 2) may be seen as a sub-system, nested in the wider context (the agro-food system, the socio-economic system), made of actors controlling technological units (blue boxes, corresponding to economic sectors), linked each other by commercial flows of goods (straight lines), where some actors may influence the behaviour of other actors by way of economic, normative and social relationships (dashed lines). This also allows for inter-disciplinary perspective of the analysis, making FSCh model a very flexible tool lending to systemic and inter-disciplinary contamination which may provide useful elements to understand disease transmission and to identify consequences in a wider context, especially in the case of FBPs and FBDs. In the next section we develop an exercise to show how this can be done.

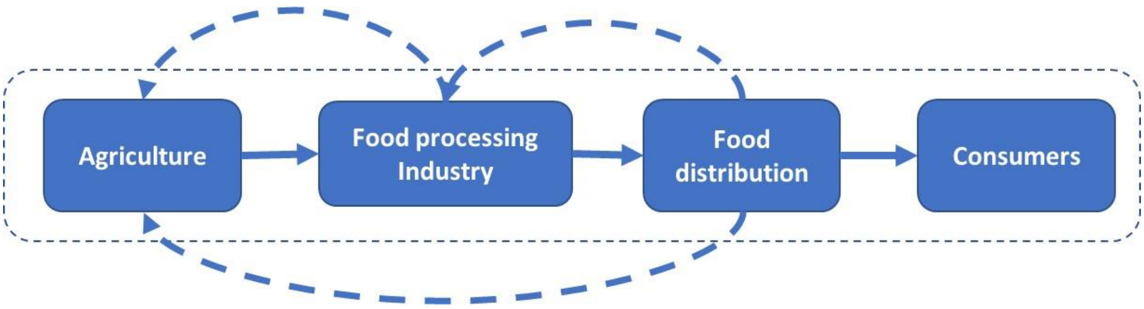


Figure 2 – Elementary representation of a food supply chain
The figure represents an elementary FSCh. The classic partition of the economic system is made of sectors (e.g. agriculture, industry, services), while the FSCh concept gathers together the activities of each sector which participate to a same aim (food production) and the consumers (dashed line box) and outlines possible feedback and relationships among sectors (dashed lines) beyond the typical product flow among sectors regulated by classical market relationships (full lines), in line with the system approach.

3. Result

In this section we propose an exercise of cost identification based on the conceptual tools described in the former section. We will refer to the case *Ech. Gran.* described in Figure 1 and we will apply simple reasoning to show how epidemiological and economic models can work together to the aim. For sake of exemplification we will also take some freedom or assumptions in the identification of the possible scenarios determined by the parasite. The starting point of the exercise may be subjective, determined by the individual understanding or by the disciplinary background of the observer. Looking at Figure 1, and considering that economics deal with the use of resources, a good starting point is the identification of the resources outlined in the figure, namely human beings, production and companion animals, fresh produce. The specific health outcomes of *Ech. Gran.* suggest that human beings may loose to some extent the ability to work which means lost working days and revenue, and bear private health care cost to re-establish from the disease. Depending on the local health care system, public health care cost may also increase. *Ech. Gran*. in bred animals may result in production losses (in this case, liver or carcasses condemnation) which ends in reduced meat sales and revenue losses for the farmers. Fresh produce may vehiculate *Ech. Gran.* especially to human being through the ingestion of contaminated materials like salads, fruits and even fruit juice (EFSA, 2018) not subject to heath treatment. Differently from meat, fresh produce doesn't undergo systematic controls by health authority, in a way that contaminated fresh produce directly enter the food chain (increasing the exposition and the risk for consumers) but do not generate immediate losses for the farmers. Pets generally do not show symptoms of *Ec. Gran.* and are not meant to produce marketable goods (just utilities for their owners). Assuming, as a mere fictional scenario, that they suffer some health consequence, their owners might be willing to spend money for care, thus increasing private health care cost (Figure 3).

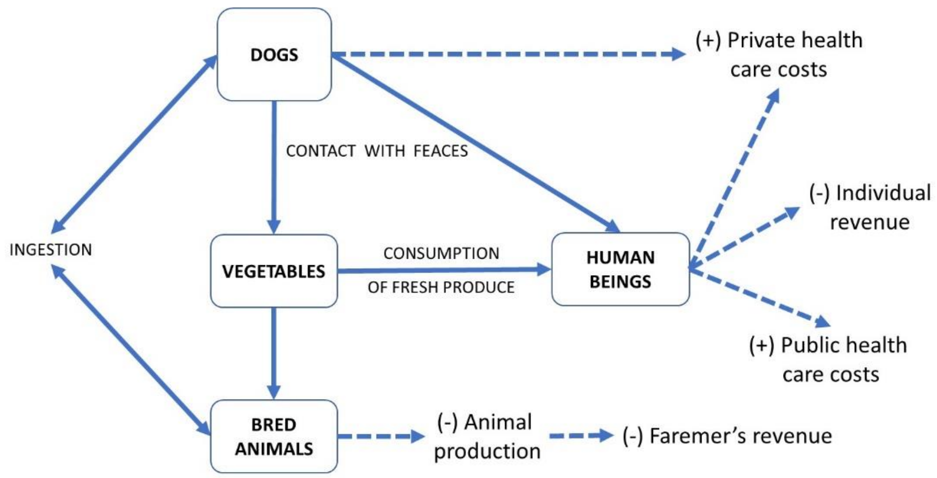


Figure 3 – Economic outcomes of *Ech. Gran*.
In this figure we consider that the basic biological units of the epidemiological model (or system) represented in Figure 1 are economic resources. As resources they have an economic value and a role for the economy (or the economic system) which is altered by the disease. This translates directly in productivity losses or in expenses in view of re-establishing the original productivity of the resource, as outlined by the dashed lines

The figure can be further elaborated expanding the range of relationships from the individual or sectoral perspective (the micro-economic and sectoral dimension of the economic system, figured by private consumers, agricultural sector, health sector) to the wide inter-sectoral and macro-economic dimension (i.e. identifying the relationship between the sub-system and other sub-system and the wider system). Just to exemplify, should health consequences of *Ech. Gran.* acquire a relevant epidemic dimension and/or the damages acquire a sectoral dimension, macro-economic effects could become important: reduction of tax revenue, public budget limit, loss of competitivity, trade balance deficit should be considered. This scenario is a fictional hypothesis and doesn't pertain current *Ech. Gran*. epidemiology but often occurs in disease outbreaks of major relevance when food alert and food occur. In those cases consumer's behaviour may change dramatically determining reversed effects backward along the FSCH with unexpected distributional effects in the economy and the society (Elci, 2006; James, 2006; Otteet al., 2006; FAO, 2016; Ramos et al, 2016;).

The reasoning above shows how the relevant units of an epidemiologic model (or system) involved in the transmission mechanism meet units and categories of the economic system allowing for a first identification of units or actors which suffer economic losses, and the kind of cost they may incur. A further structuration of the exercise in cost identification can be performed adopting the FSCh model and its expansion. Figure 4 synthesize the result of the exercise.

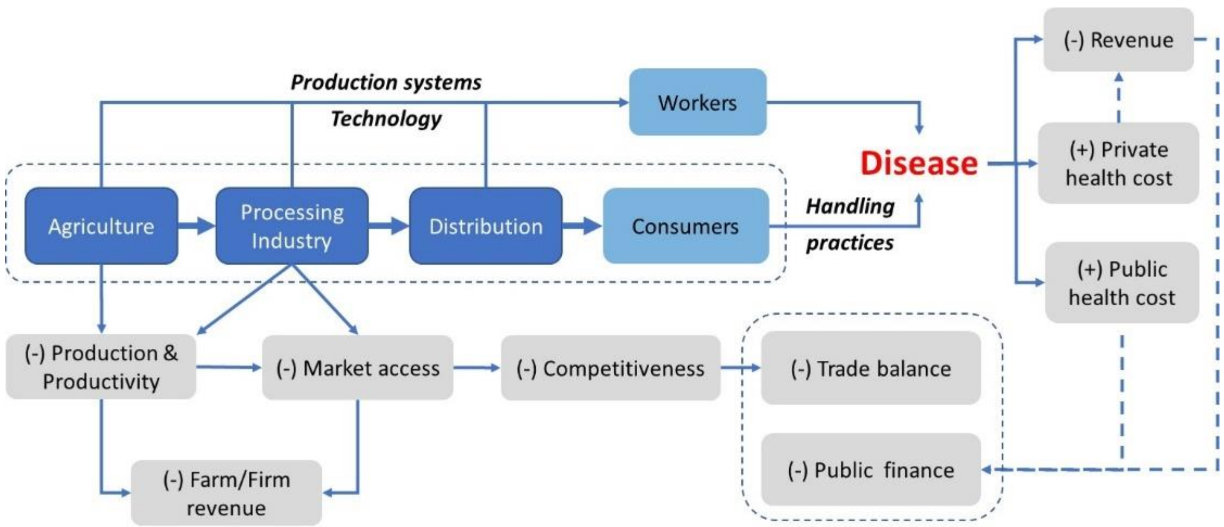


Figure 4 - Cost identification of FBDs based on FSCh model
This figure builds on the diagrams of Figure 2 and 3 to identify the wide range of effects and costs associated to the disease. Elements of the epidemiologic models are outlined in relation to production technology and consumer's handling practices. Secondly, grey boxes outline the economic mechanisms leading to sector and social costs in the wider economic system.

FBPs models show how parasites arising somewhere in human activities may affect different types of food and reach human beings. Following the FSCh steps parasites pass through the processing industry and the food distribution system and reach the consumer level. From a FSCh perspective, meat and fresh produce depict different cases because of the different processing technologies they go through and the different consumption habits of consumers (salads are washed but not cooked; industrial washing systems may not be effective on the parasites, depending on the technology and the biosecurity practices, etc.). Further, not only consumers but also FSCh workers might be exposed to disease risk. Regulation on controls along the FSCh differs between the two FSCh. The above-mentioned situations indicate that the same parasite can create different distributional effects of economic relevance, i.e. who bear what kind of cost along the two FSCh and inside the same FSCh.

The lower side of the diagram focuses the effects born by the supply chain sectors. Depending on the effects of the diseases on production animals, both farmers and meat processing industry (e.g. slaughter-houses) may suffer production and productivity losses which determine lower market access and profit losses. Fresh produce processors may be less exposed to this effect in the short run, but they may suffer the same effects later on, in case of a demand reduction following food scare. This consideration suggests another perspective for cost identification as distributional effects and related costs may change over time (immediate, short, medium or long period) and in relation to FSCh actors to food alert.

Side effects of a shortening of domestic production can lead to supplier substitution (i.e. food processors and food distributors might change food supplier) and/or product substitution (in case of food alert, consumers might decide to change product category to satisfy their needs of meat or fresh produce), paradoxically determining positive effects to competing producers or to the economic sectors producing substitute products. Through different ways, the competitivity of the FSCh at some geographical dimension would be reduced. Depending on the epidemiological dimension of foodborne disease, typical macro-economic variables could be affected: lower domestic production translates into higher import to satisfy the domestic demand (trade imbalance), while at the same time increased public health cost may demand more public funding to the detriment of alternative public expenditures. Given the usual dimension of FBDs, the latter scenario is to be considered merely fictional, but local effects might be relevant. Economic effects also have a spatial dimension

4. Concluding remarks

Methods for the identification of disease effects are a relevant preliminary step of evaluation which usually receive poor attention from the researchers in favour of the quantitative assessment through monetary and non-monetary metrics. In this paper we provided some reflection on this gap and forwarded some suggestion to outline the relevance of this activity. In particular we tried to show that interdisciplinary work and system thinking can be easily implemented by integrating epidemic models and simple, well rooted economic models, such food supply chain, a concept widely used and referred to (implicitly or explicitly) by scientists and researchers from different disciplinary domains but usually not included in a general comprehensive framework to assess disease effects and related costs.

In FBDs, food consumption is the ending point of various activities occurring at different points in time and space, across different biological systems, the environment and the socio-economic system. This makes difficult to understand the complexity FBPs and FBDs for both epidemiology and economics when an evaluation task must be performed. Using the food-supply-chain model as the analytical unit for the evaluation of FBD effects may ease the task for a scientists, administrators, practitioners who are not specialist in economics but would like to embed their specific knowledge in a wider (system) context. From an operational perspective, the exercise we developed led to the identification of the distributional effects of a FBD in different directions (i.e. sub-systems). We reasoned about the way FBD may hit consumers, in relation to their consumption habits and food handling practices; economic sectors (agricultural production, industrial processing, food distribution) depending on production systems and processing technologies; social categories depending on their position along the food supply chain (consumers of different type of food, and FSCh workers). Other considerations concerned the way relevant elements of the epidemiological disease (i.e. fresh produce vs meat) can start different series of economic effects depending on food practices and technologies and institutional settings (e.g. the type of controls imposed by the public health system on different type of food). Finally, we suggested that disease effects and costs can be distributed along the timeline (by including possible reactions of consumers and producers to food alert), the space (potential effects of supplier substitution in geographically defined markets) and within the food supply system (product substitution that could paradoxically benefits some producers during the food scare).

The other face of the medal is the difficulty of integrating conceptual models from different academic disciplines and institutions, an aspect which call into question the inter-disciplinarity and trans-disciplinarity and the way different knowledges can be coordinated. In practice, team working is probably the frontline of interdisciplinarity (Aragrande and Canali 2015). Simple tools of team management do exist and can be easily implemented, but this requires some investment (usually time and organization) to be evaluated in a cost-benefit perspective (how much understanding and problem solving can improve against the above-mentioned investment?). The increasing trend toward One Health approach to health problems may provide some indication and motivation in this sense.

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