Genetically modified animals in the food and pharmaceutical chains: economics, public perception and policy implications

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Summary

This paper presents ongoing results of the EU project PEGASUS (Public Perception of Genetically modified Animals – Science, Utility and Society, 7th FP).The overall objective is to provide support for future policy regarding the development, implementation and commercialisation of genetically modified (GM) animals, both terrestrial and aquatic, together with the foods and pharmaceutical products derived from them. Food products derived from GM animals have not yet entered the market. Nonetheless, the ongoing discussion about GM crops and the recently initiated discussions about the safety and ethics of foods and pharmaceutical products derived from cloned animals have set the stage for the socio-economical issues that will surround the introduction of GM animals in the food and pharmaceutical chains. This papers shows the economic and governance pros and cons of GM applications in the animal and pharmaceutical chains, as well as the factors affecting their adoption. Public and producers acceptance, technical improvements and public policies are considered as the main factors affecting the application of GM animals techniques in livestock and pharmaceutical chains.

Keywords: genetically modified animals, public perception, economic impact, policy implications
Q16; D18, I12.

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1. INTRODUCTION

The PEGASUS project aims to provide policy support regarding the development, implementation and commercialisation of GM animals and derivative foods and pharmaceutical products. Foods and pharmaceutical products derived from genetically modified (GM) animals have not yet entered the European market. Nonetheless, the ongoing discussion about GM crops and the recently initiated discussions about the safety and ethics of foods and pharmaceutical products derived from cloned animals have set the stage for the societal issues that will surround the introduction of GM animals, if the policy decision to proceed with their introduction is arrived at.

From a historical point of view, Europe has had a leading role in the development of cloned and GM animals throughout the 90s. Notable examples include the sheep "Dolly" being the first animal created by cloning through transfer of a cell nucleus from a differentiated cell to an egg cell, at the Roslin Institute in Scotland. Another example is the bull "Herman," which had been developed by the Dutch biotechnology company Gene Pharming Europe. Genetic modification had been applied so that subsequent generations of female offspring would produce the protein lactoferrin through their milk, which can be used for food, nutraceutical, and pharmaceutical purposes. Other experimental animals have been developed within European institutions, including genetically modified fish and chicken, with specific advantages and benefits to food production and other areas of application.

Despite considerable European innovations occurring in the area of GM animal technology, many of the current activities in the field of GM food animals take place outside the EU, in particular regions like the Far East, North America, and Australia-New Zealand. It can be envisaged that some of these animals still find their way into the European food supply chain through imports from overseas, in particular given that the EU is the world's largest international trading block for food commodities.

This paper aims to provide insights into the economic advantages and disadvantages of genetically modified animals application in food and pharmaceutical chains (Section 2), and the main factors affecting their adoption (Section 3). In particular, the role of consumers acceptance and public policies will be discussed in detail.

2. ECONOMIC EFFECTS OF GENETICALLY MODIFIED ANIMALS

The production of transgenic animals can be considered as an emerging technique expected to have a deep impact on the genetic improvement of livestock. Transgenic or genetically modified (GM) animals are organisms generated with segment of foreign DNA introduced into their genome or with any modification

introduced in their genome sequence. Transgenic animals have different potential applications that can be divided into three major categories: i) to obtain information on gene function and regulation as well as on human diseases, ii) to obtain high value products to be used for human therapy (biopharming and xenografting), and iii) to improve quantitative and/or qualitative animal production for human consumption (Houdebine, 2005). In this review we focus on the two latter categories. A scoping study was performed to evaluate economic advantages (pros) and disadvantages (cons) of GM animals applications from a production chain perspective.

Scoping studies aim to map the key concepts underpinning a research area and the main sources and types of evidence available (Arksey and O'Malley, 2005). After the definitions of the scoping study guidelines to identify relevant papers (keywords, journals, web sources, etc.), by key terms, according the research questions (what are the economic and governance aspects of GM animals introduction in food chains and pharmaceutical chain and what are the methodologies utilised in the analysis). The search strategy for electronic databases (e.g. internet, CD-Rom, etc.) has been developed from the research questions and definitions of keywords and key concepts for the period 1996-2010. All the information of the relevant papers were collected and standardized into a "data charting form". This form included general information about each study (year, aim of the study, source, etc.) and more specific information (e.g. type of genetic modification, economic effects, governance issues, methodology, main results, factors affecting the adoption of GM technologies, geographical location, outcome measures, data source, secondary results, etc.).

We have collected 145 studies from different sources; 55 were significant to identify what are the economic and governance aspects of GM animals introduction in food chains and pharmaceutical chain and 33 were studied for the review of the existing methods used to identify these aspects. Eight papers were significant for both topics. Most of the selected studies involved food chains and only few pharmaceutical chains; half of the studies were reviews of transgenic applications and only one third empirical analysis. Many studies were published between 2002 and 2003 (30%), as well as in more recent year (25% after 2007). The type of animals involved in the reviewed studies were mostly bovine, fish and swine, showing a marked interest of the research applied with these species (Mora et al., 2011).

2.1. Economics of GM fish in aquaculture

The interest in GM development in aquaculture is stronger than for terrestrial animals for three reasons: fish eggs can be more easily manipulated, fish farming is still a rapidly growing market compared to the meat market (Aerni, 2004) and in many countries fish is still a rather expensive product. The most commonly developed and economically valuable GM fish is characterised by accelerated growth and food conversion, improved cold tolerance or freeze resistance, improved disease resistance, altered metabolism (e.g. to reduce the requirement for fish-based diets by salmonid fish), sterilisation and fish pharming (Beardmore & Porter 2003; Maclean, 2003; Aerni, 2004). Around 50 species of fish have been subject to genetic modification with over 400 fish/trait combinations (Cowx, et al., 2010). In particular, the U.S. Food and Drug Administration (FDA) is now considering whether to approve for marketing a GM Atlantic salmon which grows faster and requires less feed to grow (Smith et al., 2010). The growth-enhanced GM salmon could become the first genetically engineered animal approved for human consumption. However, others argue that it is possible that GM fish have been already commercialized; there have been reports of extensive trials of growth-enhanced GM tilapia in Cuba (30 tons of transgenic tilapia reaching supermarket shelves in 1999) and, similarly, it is possible that growth-enhanced GM carp have been farmed for market in China; in both cases, information is scarce and conflicting (Maclean, 2003).

The economic effects of transgenic fish range from positive effects to negative effects. The economic impact of growth-enhanced GM fish can be enormous: this fish would benefit growth rates markedly superior to non-GM fish. Studies have revealed acceleration of growth particularly in salmonids reaching full market size in less than one-half the time required for non-transgenic fish of the same species (Entis, 1998; Melamed, 2002; Beardmore & Porter 2003; Maclean, 2003). Tilapia has also experienced good responses, with a twofold up to threefold enhancement for first generation progeny (Maclean, 2003). Moreover, feed conversion ratio (FCR), that is the amount of body weight gained for every kilogram of feed consumed is expected to be more efficient (Clifford, 2009; Entis, 1998). This may be a significant economic advantage if we consider that feed costs represents more than 50% of total operating costs of salmon famers. Production unit costs of GM growth-enhanced salmon has been estimated to decrease by 20% (Entis, 1998) up to 50% (Lutter & Tucker, 2002). This cost reduction may lead to an increase of world production and to a consequent reduction of market prices (Lutter & Tucker, 2002; Smith et al., 2010). As noted by Smith et al. (2010), price reduction could stimulate fresh GM and non-GM salmon consumption in low-income households susceptible to conditions linked to poor nutrition, thus achieving high marginal benefits in public health. Similar effects, although less relevant, may be foreseen for other fish modifications like increased resistance to and pathogens, and altered metabolism (Melamed, 2002; Maclean, 2003; Le Curieux-Belfond et al., 2009).

However, the potential environmental impact of escaped GM fish on wild species has dominated the discussion and impeded its approval so far. Biological and physical containment measures may address these environmental concerns. GM fish should be sold sterile (triploid) and single sex (female), only to growers who raise them in secure confined systems (Cowx, et al., 2010). However, these facilities cost 40% more to build and 60% more to operate than sea cages (Aerni, 2004). This could partially reduce the appeal of these products.

2.2. Economics of GM animals in livestock food chains

In general, the economic effects of transgenic animals on the market will depend on how the biotechnology affects costs of production, product quality, or both (Caswell et al., 2003). Basically, from an economic point of view, biotechnologies, either crop or animals, can be divided into two broad category: a) cost reducing/quantity enhancing and b) quality enhancing.

Cost reducing and quantity increasing technologies can potentially increase producers profits by allowing to produce a given amount of a product at lower cost or, in alternative, a higher amount of product at the same cost. This, in a competitive market, will traduce, in the long run, to a downward pressure on food market prices which, in turn, will benefit consumers whilst potentially offset the producers' profit increase (Caswell et al., 2003)[1].

Quality-enhanced food products can potentially increase producer profits by increasing the demand for the improved food. Quality-enhanced food can be theoretically sold on the market at higher prices compared to the conventional food, if consumers' value the quality change. New niches will be created and, consequently, the market will be segmented, modifying the entire production chain (Melo et al., 2007). Thus,

[1] The extent to which consumers and producers would benefit from such applications will depend on demand elasticity (sensitivity) to price changes. If demand is fairly inelastic with respect to price (a strong increase in price reflects a slightly decline in demand, and vice versa), a supply increase will cause a sharply fall in market prices, while maintaining almost the same quantity demanded. In this case, the transgenic animal introduction will greatly benefit consumers while decreasing producers benefits. On the other hand, if demand is price elastic, the increase in supply would result in a small decline in prices and a large increase in the quantity demanded. In this case, producers will benefit relatively more compared to consumers. However, this model assumes that consumers don't care which process was used to create the cheaper commodity, which might not be the case for transgenic animals.

because of the market segmentation between a high quality and a low quality food, the distribution of benefits are more difficult to evaluate (Caswell et al., 2003)[2].

Applications aiming to increase the input efficiency, to improve animal welfare through increased diseases resistance, to increase carcass and milk production yields and to increase reproductive performances are examples of cost reducing or quantity enhancing projects. An approach to increase sow milk production has been accomplished by alteration of milk components such as lactose. The economic effects of a more efficient and optimal pork production, reliant upon the production of healthy, fast growing piglets, have been estimated: an increase in milk production by 10% would result in an additional $2.46 per litter that, considering typical hog price of $50/cwt, would generate an overall economic benefit in the U.S. pork industry of $28.4 million/year (Wheeler, 2003). Another interesting application to pigs is the so called Enviropig^{TM}; it has been noted that the production of GM pigs expressing salivary phytase would provide complete digestion of dietary phosphorus, reducing phosphorus output by 20% up to 75% with clear environmental benefit (Golovan et al., 2001). Also, this application may also result in an economic advantage considering that conventional pigs require around 2.5 kg of supplemental dicalcium phosphate for weaning to market weight, whereas transgenic pigs can potentially recover sufficient phosphorus for optimal growth from phytate present in normal feed (Golovan et al., 2001). The struggle against animal diseases appears now the most important issue able to improve animal welfare and reducing production costs. The disease costs are estimated to be 35–50% of turnover in developing countries and 17% in the developed world (Sang, 2003). GM animals would reduce the use of drugs, particularly of antibiotics in some cases, reduce loss and enhance yield in breedings, and reduce the frequency of animal disease transmission to humans (Houdebine, 2005). The economic advantages may be dramatic considering that only mastitis cost the U.S. dairy industry about $1.7 billion/year (Melo et al., 2007).

Quality enhancing applications have been developed mostly to improve milk composition, although other projects attempted to improve meat quality as well as other non-food characters (Wheeler, 2007). An attractive example for genetic modification is dairy production. Bovine have been generated that are able to over-express in their milk recombinant human lactoferrin (rhLF). It has a wide range of possible applications in human health care, such as prophylaxis and treatment of infectious and inflammatory diseases (van Berkel et al., 2002). Although this application is expected to be applied principally in the biopharmaceutical industry, dairy milk with rhLF represents a functional food that might offer new health benefits such as increased protection against infections, improved gastrointestinal health, making it more appropriate to the consumption of infants (Laible, 2009).

To improve the quality of pork meat, it was found that the IGF-1 transgene helped reduce carcass fat and boost lean body mass, making each hog worth $6 more on the market (Novoselova et al., 2007). Similarly, pigs were engineered for the production of endogenous omega-3 fatty acids, implicated in prevention of coronary disease (Lai et al., 2006). This has been argued to be a more economical, safe and sustainable strategy to enrich meat compared to the current practice of feeding animals with fishmeal in order to satisfy the growing demand for omega-3 fatty acids in human nutrition. The publication of that study has stimulated an interesting debate opposing those in favour with those against to the marketing of omega-3 pig meat. Interestingly, the latter stated that "we are altering the genome of an animal to enable consumers to continue with their self-destroying eating habits" (Fiester, 2006), i.e. eating junk food. As a response, authors

[2] Consumers preferences for the two products will affect the new market equilibrium; however, if market segmentation is effective and information is symmetrically distributed in the market (i.e. both high and low quality food products are properly traced and labeled), consumers of both products will benefit from lower prices and increase variety.

of the research affirmed that omega-3 pigs may reduce by 40% the risks of sudden cardiac deaths, noting that it is easier to improve health by modifying food than by changing consumers' habits (Kang & Leaf, 2007).

2.3. Economics of GM animals in pharmaceutical chains

The conventional production of human therapeutic proteins from blood or tissue extracts is an inefficient, expensive labour and time consuming process, bearing the risk of contamination with human pathogens (Kaye-Blake et al., 2007). The production of human therapeutic proteins by recombinant bacteria or cell cultures has alleviated these problems and has made several therapeutic proteins available for patients. However, these recombinant systems have several technical limitations and can only be produced at high production costs (Kues & Niemann, 2004). Biopharming is the production of pharmaceutical compounds in plant and animal tissue in agricultural systems and it is considered as the next major development in both farming and pharmaceutical production (Kaye-Blake et al., 2007). For farmers, the appeal of biopharming is the production of high-value, niche products, which moves traditional agriculture away from commodity production. For pharmaceutical firms, biopharming promises a method for reducing production costs significantly compared to cell culture (Kaye-Blake et al., 2007). For instance, the cost per gram of purified immunoglobulin IgA made by cell culture (US$1000 g^{-1}) is ten times higher than transgenic goats (US$100 g^{-1}) (Daniell et al., 2001). For the general public, the benefits of biopharming would be cheaper drugs produced more quickly (Kaye-Blake et al., 2007). Benefits of biopharming compared to cell culture production methods are lower production and storage costs, easier distribution, easier propagation, higher protein yields, higher safety and lower time required.

Although the biopharming approach seems feasible, the financial commitment required during the protracted development phase has halted many attempts at commercial exploitation. Over the past few years several commercial ventures have withdrawn from transgenic biopharming for various reasons (Clark & Whitelaw, 2003). Not surprisingly, we have two cases of drugs on the market produced from GM animals tissues: the recombinant protein ATryn® (human antithrombin-III) produced in transgenic goats' milk approved in the EU in 2006 (Houdebine, 2009b) and the Rhucin®, a recombinant C1-inhibitor produced by a GM rabbit, in 2010 (Vàzquez-Salat et al., 2012). So, even though much of the groundwork has been done it is unclear what the future holds for this use of transgenic livestock.

The use of polyclonal antibody therapeutics is undergoing a revolution. Monoclonal antibodies are described as 'sniper bullets' targeting a single specific epitope while polyclonal therapy may be described as 'machine gun' approach (Newcombe, 2007). Another advantage of polyclonal antibodies raised against a selected target in hyperimmunized animals is that most immunogenic epitopes are naturally selected for by the host. Thus, a number of new approaches involving biochemical path ways, immunotherapy and vaccine strategies utilizing Cytokine derivatives, viral toxins or cellular factor are being evaluated by biopharmaceutical companies for treatment of a number of diseases like AIDS, cancer, and some allergies. For instance, Neovacs SA (Paris, France) is engaged in the development of anti-Cytokine therapeutics for treatment of HIV infections. Generation of recombinant polyclonal antibodies for colorectal cancer therapy has also been reported recently. With these kind of advancements, the future looks bright for polyclonal-derived antibody therapeutics.

3. FACTORS AFFECTING THE ADOPTION OF GM ANIMALS

The main factors affecting introduction of GM animals techniques to livestock and pharmaceutical chains range from public and producers acceptance to public policies.

3.1. Public acceptance

Consumer acceptance is generally considered as a "condicio sine qua non" for any development of transgenic animals in food and pharmaceutical chains. The uncertainty of consumers' reaction is the largest issue in assessing the potential of animal biotechnologies worldwide (Caswell et al., 2003). The framework suggested for technology adoption, therefore, takes the consumer as a starting point. Consumers' attitude (positive vs. negative) and concerns (health, food safety, unnaturalness, ethical, environmental, animal health and welfare, etc.) are fundamental factors to understand GM adoption and public perceptions of GM technology. These issues have been the focus of several researches (Novoselova et al., 2007; Frewer et al., 2011).

Many studies show that public acceptance of modern biotechnology is lowest where food or animals are involved (Gaskell et al., 2000; Aerni, 2004). For instance, a FAO global pool reports that 62% of all respondents worldwide opposed the application of biotechnology to increase farm animal productivity. Another example is a survey performed for the Pew Initiative on Food and Biotechnology; it indicates that 65% of consumers disagree with the idea of creating transgenic fish to improve efficiency of production (Logar & Pollock, 2005).

Another study suggests that end-user acceptance of biotech varies considerably by application area and by world geography (Devlin et al., 2009). Medical and pharmaceutical biotechnology related to GM animals is generally accepted by most, due to perceived personal benefits. The public acceptance is higher compared to other GM applications, ranging from 83% in developing countries to 70% in Japan (Devlin et al., 2009). Fish biotechnology shows the lowest acceptance rate of all areas being considered. The low tolerability for GM fish may stem for several factors including environmental concerns. If geographic differences are considered, consumers acceptance is higher for developing countries where the need for enhanced food production might benefit most strongly by application of this technology (Devlin et al., 2009).

The fact that plant applications received higher support than animal applications has also been reported by another research carried out in the U.S. (Knight, 2006). Animals to be resistant to diseases were the most accepted among livestock-derived products, whereas animals producing more tasty and tender meat, human organs and increasing production were, respectively, the least supported by respondents.

Some empirical studies analyzed consumer acceptance for specific GM products, e.g. reporting a higher consumer preference of conventional over GM pork (Novoselova et al., 2005). In this case, the negative perception of GM pork may be compensated by improvements in quality, increased animal health and welfare (Greger, 2011), a lower impact on the environment, less residues and a price discount. Increased animal welfare has provided the most positive effect on consumer choices, whereas improvement in environments receives the lowest utility. This means that, according to this study, with substantial monetary compensation and presence of various benefits consumers would attach higher utility to transgenic than conventional pork. The amount of monetary compensation is also dependent on GM application (Novoselova et al., 2005).

Price discount is the most quoted personal benefit for accepting GM salmon (Kuznesof & Ritson 1996, Grunert et al. 2001, Bennet et al. 2005). Other benefits associated with GM salmon consumption are environmental benefits (Grunert et al. 2001, Bennet et al. 2005) and health benefits resulted from higher

omega-3 intake (Qin and Brown 2006); consumers were more accepting of GM foods if their production reduced the need for chemical usage (Bennet et al. 2005) or used less fodder (Grunert et al. 2001). The consumers' low acceptance results in high price discounts asked by consumers for buying GM salmon, or premium price to avoid this product (Kaneko & Chern 2005, Chen & Chern 2004, Chern & Rickertsen 2004, Grimsrud et al. 2002). Consumers acceptance in the U.S. is higher than in Europe, denoting a higher price discount required for European consumers (Chern & Rickertsen 2004). Other important factors, like environmental sustainability, human health effects, animal health and welfare and ethical concerns may also affect consumer acceptance.

A study conducted in the PEGASUS project has analysed 70 papers containing data (or data which could be accessed by contacting the authors) which were amenable to formal meta-analysis (Frewer et al., 2012). The results indicate that consumers intention to use the products of GM animals were lower than for GM plants or for GM applications in general, independent of region. Intentions to purchase the products GM organisms of Europeans were more negative than those observed in SE Asia and North America. Similar results were observed for overall attitude. North Americans perceived more benefits associated with GM overall when compared to Europeans and Asians. However, benefit perception increased with time in all of the regions for which analysis was possible. This effect occurred independent of whether the target of the application was focused on GM animals, plants or generic applications. North American, South American and Asian participants perceived fewer risks than Europeans. Risk perception increased with time independent of region, independent of target organism. In contrast, ethical and moral concerns were greater in North America and Asia compared to those within Europe.

3.2. Producers acceptance

Similarly to consumers, also producer may have concerns in the adoption of a new technology. Uncertainty surrounding the way the technology will perform in the future, concerns related to increased dependency on input suppliers, expectations of higher input prices, uncertainty of the results and of the likely consumer acceptance, are among the main producers' concerns cited in the literature reviewed (Melo et al., 2007; Novoselova et al., 2007). It is also clear that producer acceptance will depend on the benefits expected from the GM application (reduction of feeding costs, increase yields, etc.) and on how costs and benefits are distributed across the chain. It is often argued that the costs of technology adoption occur in one stage of the chain, while the benefits are perceived in another stage (Novoselova et al., 2007).

In the specific aquaculture case, it has been suggested that a company that produces a new growth-enhanced salmon may not just face scepticism from consumers, but may also be shunned by the fishery industry itself. Established local fish producers might fear new competition from transgenic fish and a radical change in the market structure of the sector. In turn, retailers, which wields most market power in the food business and value consumer concerns more strongly than producers' innovative strategies, may be unwilling to buy transgenic fish and run the risk of being ostracized by their customers. Companies may nevertheless be afraid of anti-GMO campaigns performed by activist groups which might negatively affect the public image of the brand (Aerni, 2004).

3.3. Policy implications

Public policies affect the profitability of private R&D investment through mechanisms that include direct public funding of research, intellectual property rights legislation, regulatory policies, financial and tax policies, education policies and other policies covering the environment and industry (Caswell et al., 2003).

Several documents have been produced to provide insights in governing products derived from transgenic animals (Gavin, 2001; Kleter & Kok, 2010). Food safety and environmental risk assessments are considered as fundamental steps to deal with these new technology applications. It has also been argued that, as decisions made by one country may affect the others, different approaches to decision-making process should be as much as possible harmonized (Le Curieux-Belfond et al., 2009).

Intellectual property rights (IPR, that is patents, trademarks and copyrights) influence a firm's incentive to invest in R&D by enhancing a firm's ability to capture rent and profits resulted from the innovation (Caswell et al., 2003). In the case of biotechnology and transgenic animal in particular, this is a very difficult issue. The transgenic animals patent debate is not confined to technical and legal arguments and have extended over ethical and political issues, including public opinion. Many products of nature (like specific antibiotics, microorganisms, protein etc.) have been successfully patented protecting the innovators right to reproduce. But it is debatable to categorize a naturally occurring substance as patentable, as it lacks novelty and inventive step. However if product is enriched, purified or modified of nature in an industrially useful format, it is then patentable. Biological materials which previously existed in nature are patentable provided they must be purified from natural environment and must confirm to the general patentability principles regarding novelty, non-obviousness, utility and sufficiency of disclosure (Daneshyar et al., 2006).

The future of private industry funding for biotechnology R&D will be influenced by the regulations that are in force. In particular, environmental and food safety regulations are expected to affect the profitability of R&D by i) increasing the costs of developing new technology by extending the time necessary to bring a product to market and ii) increasing the cost of meeting stricter standards (Caswell et al., 2003). Regulatory policy and industry practices associated with transgenic livestock must be transparent and effectively communicated to achieve consumer acceptance (Kochhar & Evans, 2007). Strict control of an animal or a herd starts at the level of identification. Reliable and permanent identification is already available in livestock industry in many forms (ear tags, ear tattoos, external electronic transponders, subcutaneous electronic transponders, etc.) and it is prudent to use redundant systems (Gavin, 2001).

Labelling and information policies could be a solution in helping consumers to make a deliberate choice and in helping producers to differentiate their products. Assuming that GM animals and derived products will be properly labelled in the EU once approved and commercially available, it is questioned whether the food obtained from GM animals must be labelled in other markets. The U.S. FDA is now debating whether the GM salmon could be labelled (U.S. Food and Drug Administration, 2010), although this would lead to a different solution compared to food from GM crops. Labelling regulations will lead to extra costs, among others the costs of traceability (Novoselova et al., 2007). Monetary costs associated with tracing and labelling biotech-derived animals and their products have to be taken into account, as well as other costs that might become necessary to fulfil the regulatory requirements (e.g. physical containment for GM fish). The costs of complying with regulations will likely reduce the private profitability of the technology, but the public will benefit from reduced risk. Thus, the balance between the costs and benefits of the regulation will determine the social cost-effectiveness of the regulation (Caswell et al., 2003).

4. CONCLUSIONS

The production of transgenic animals, that potentially can have a deep impact on the livestock and pharmaceutical chains, has proceeded much slower than genetic modification of crops. Improvements in animal biotechnology are expected to result in economic benefits for farmers, processors and consumers, the distribution of which depends on the type of technology (cost reducing/quantity enhancing or quality enhancing applications), market structure and competitiveness (concentration ratio, suppliers market power,

etc.), information transparency (labelling and traceability programs, etc.), price elasticity, consumer acceptance, etc. Beside the direct economic effects, other externalities, both positive and negative, should be considered in the overall economic evaluation.

The interest in GM development in aquaculture is stronger than for terrestrial animals due to several factors such as better growth rates in fish and improved feed conversion rates, that may result in a significant production costs reduction, thus reduction in the market price, the potential economic impact of the introduction of GM fish could be enormous. The case of growth-enhanced GM salmon shows that benefits for producers, arising from increased growth rates and food conversion rates, may lead to a relevant reduction in production costs and to an increase in gross margin. At the same time, environmental and human health risks should be deeply considered in the overall evaluation of the transgenic fish introduction. Indeed, the high ecological concerns associated with the GM fish farming may require the adoption of physical containment strategies, which may potentially limit the economic attractiveness of GM fish.

Biopharming is new territory for the agricultural and pharmaceutical industries, and presents novel challenges for government regulators and others. Due to the high cost, the production of transgenic animals such as pig, goat, sheep and cattle must bring an elevated profit in order to be a feasible economical investment. For this reason, the production of high-value pharmaceutical substances, which correspond to a billion dollars market, is actually the principal and most promising application for animal transgenesis. However, the financial commitment required during the protracted development phase has halted many attempts at commercial exploitation and, at present, two drugs produced in this way has reached the market.

Given the rapid development of these technologies and the intense GM debate of the 1990s, some governments are beginning to produce a regulatory response to the marketing of GM animals. Experts argue that the distinction between USA and EU approaches that in the past has accompanied the development of GM crops, might be less marked in the case of GM animals (Vàzquez-Salat et al., 2012). Both players are going to face stakeholders' adversity, e.g. from animal welfare organizations, and a lower positive pressure from multinational companies. The regulatory strategy adopted by these global players will affect their ability to exploit these biotechnologies commercial potential as well as the international trade. In this context international bodies, such as FAO, World Health Organization (WHO) and World Organization for Animal Health (OIE), will have an important role in providing forums for neutral discussion and encouraging harmonization on the food sector (Vàzquez-Salat et al., 2012).

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REFERENCES

Arksey H., O'Malley L. (2005). Scoping studies: towards a methodological framework. *International Journal of Social Research Methodology*, 8:19 - 32.

Aerni, P. (2004). Risk, regulation and innovation: The case of aquaculture and transgenic fish. *Aquatic Sciences, 66*, 327-341.

Beardmore, J. A., & Porter, J.S. (2003). Genetically modified organisms and aquaculture. *FAO Fisheries Circular*, 38.

Bennett, B., D'Souza, G., Borisova, T., & Amarasinghe, A. (2005). Willingness to consume genetically modified foods—the case of fish and seafood. *Aquaculture Economics & Management, 9*, 331-345.
Caswell, M.F., Fuglie, K.O., & Klotz, C.A. (2003). *Agricultural biotechnology: an economic perspective*. New York: Novinka book.
Chen, H-Y., & Chern, W.S. (2004). Willingness to pay for GM foods: results from a public survey in the USA. In R.E. Evenson, & V. Santaniello (Eds.), *Consumer acceptance of Genetically Modified Foods* (pp. 117-129), London: CABI Publishing.
Chern, W.S., & Rickertsen, K. (2004). A comparative analysis of consumer acceptance of GM food in Norway and the USA. In R.E. Evenson, & V. Santaniello (Eds.), Consumer acceptance of Genetically Modified Foods (pp. 95-109), London: CABI Publishing.
Clark, J., & Whitelaw, B. (2003). A future for transgenic livestock. Nature Reviews Genetics, 4, 825-833.
Clifford H.C. (2009), AquAdvantage® Salmon – A pioneering application of transgenics in aquaculture, First national conference of biotechnology, May 12th – 13th, Lima, Peru.
Cowx, I. G., Bolland, J. D., Nunn, A. D., Kerins, G., Stein, J., Blackburn, J., et al. (2010). Defining environmental risk assessment criteria for genetically modified fishes to be placed on the EU market, Scientific/Technical Report submitted to EFSA, Parma: EFSA.
Daneshyar, S.A., Kohli, K., & Khar, R.K. (2006). Biotechnology and intellectual property. *Scientific Research and Essay, 1*, 020-025.
Daniell, H., Streatfield, S. J., & Wycoff, K. (2001). Medical molecular farming: production of antibodies, biopharmaceuticals and edible vaccines in plants. *TRENDS in Plant Science, 6*, 219-226.
Devlin, R.H., Raven, P.A., Sundstrom, L.F., & Uh, M. (2009). Issues and methodology for development of transgenic fish for aquaculture with a focus on growth enhancement. In K. Overturf (Ed.), *Molecular research in aquaculture*, Ames (Iowa): Wiley-Blackwell publishing.
Entis, E. (1998). AquAdvantage™ salmon: a case study in transgenic food. *Animal Biotechnology*, *9*, 165-170.
Fiester, A. (2006). Why the omega-3 piggy should not go to market. *Nature Biotechnology, 24*, 1472-1473.
Frewer, L.J., Bergmann, K., Brennan, M., Lion, R. Meertens, R., Rowe, G., Siegrist, G., & Vereijken, C. (2011). Consumer response to novel agri-food technologies: Implications for predicting consumer acceptance of emerging food technologies. *Trends in Food Science and Technology, 22*, 442-456.
Frewer, L.J., van der Lans, I., Fischer, A.R.H., Reinders, M.J., Menozzi, D., Zhang, X., van den Berg, I. and Zimmerman, K. (2012). Public perceptions of agrifood applications of Genetic modification – A systematic review. Deliverable D1 - PEGASUS project.
Gaskell, G., N. Allum, M. Bauer, J. Durant, A. Allansdottir, H. Bonfadelli, D. Boy, S. de Cheveigné, B. Fjaestad, J. M. Gutteling, J., Hampel, E. Jelsøe, J. C. Jesuino, M. Kohring, N. Kronberger, C., Midden, T. H. Nielsen, A. Przestalski, T. Rusanen, G. Sakellaris, H. Torgersen, T. Twardowski & W. Wagner (2000). Biotechnology and the European Public. *Nature Biotechnology, 18*, 935–938.
Gavin, W.G. (2001). The future of transgenics. *Regulatory Affairs Focus, May 2001*, 13-18.
Golovan, S.P., Meidinger, R.G., Ajakaiye, A., Cottrill, M., Wiederkehr, M.Z., Barney, D.J., Plante, C., Pollard, J.W., Fan, M.Z., Hayes, M.A., Laursen, J., Hjorth, J.P., Hacker, R.R., Phillips, J.R., & Forsberg, C.W. (2001). Pigs expressing salivary phytase produce low-phosphorus manure. *Nature Biotechnology, 19*, 741-745.
Greger, M. (2011). Transgenesis in animal agriculture: addressing animal health and welfare concern. *Journal of Agricultural and Environmental Ethics*, *24*, 451-472.
Grimsrud, K.M., McCluskey, J.J., Loureiro, M.L., & Wahl, T.I. (2002). Consumer attitudes toward genetically modified food in Norway. *American Agricultural Economics Association Annual Meeting*, July 28–31, Long Beach, California.
Grunert, K.G., Lahteenmaki, L., Nielsen, N.A., Poulsen, J.B., Ueland, O., & Astrom, A. (2001). Consumer perceptions of food products involving genetic modification—results from a qualitative study in four Nordic countries. *Food Quality and Preference, 12*, 527–542.
Houdebine, L.M. (2005). Use of transgenic animals to improve human health and animal production. *Reproduction in Domestic Animals*, *40*, 269-281.
Houdebine, L.M. (2009a). Applications of genetically modified animals. *Journal de la Société de Biologie, 203*, 323-328.
Houdebine, L.M. (2009b). Production of pharmaceutical proteins by transgenic animals. *Comparative Immunology Microbiology and Infectious Diseases, 32*, 107-121.

Houdebine, L.M. (2011). Production of human polyclonal antibodies by transgenic animals. *Advances in Bioscience and Biotechnology, 2*, 138-141.
Kaneko, N., & Chern, W. (2005). Willingness to Pay for Genetically Modified Oil, Cornflakes, and Salmon: Evidence from a U.S. Telephone Survey. *Journal of Agricultural and Applied Economics*, *37*, 701-719.
Kang, J.X., & Leaf, A. (2007). Why the omega-3 piggy should go to market. *Nature Biotechnology, 25*, 505-506.
Kaye-Blake, W., Saunders, C., & Ferguson, L. (2007). *Preliminary Economic Evaluation of Biopharming in New Zealand*. Agribusiness and Economics Research Unit Report 296, Lincoln (New Zealand): Lincoln University.
Kleter, G.A., & Kok, E.J. (2010). Safety assessment of biotechnology used in animal production, including genetically modified (GM) feed and GM animals – a review. *Animal Science Papers and Reports, 28*, 105-114.
Knight, A.J. (2006). Does Application Matter? An Examination of Public Perception of Agricultural Biotechnology Applications. *AgBioForum, 9*, 121-128.
Kochhar, H.P.S., & Evans, B.R. (2007). Current status of regulating biotechnology-derived animals in Canada--animal health and food safety considerations. *Theriogenology, 67*, 188-197.
Kues, W.A., & Niemann, H. (2004). The contribution of farm animals to human health. *Trends in Biotechnology*, *22*, 286-294.
Kuznesof, S., & Ritson, C. (1996). Consumer acceptability of genetically modified foods with special reference to farmed salmon. *British Food Journal, 98*, 39–47.
Lai, L.X., Kang, J.X., Li, R.F., Wang, J.D., Witt, W.T., Yong, H.Y., Hao, Y.H., Wax, D.M., Murphy, C.N., Rieke, A., Samuel, M., Linville, M.L., Korte, S.W., Evans, R.W., Starzl, T.E., Prather, R.S., & Dai, Y.F. (2006). Generation of cloned transgenic pigs rich in omega-3 fatty acids. *Nature Biotechnology, 24*, 435-436.
Laible, G. (2009). Enhancing livestock through genetic engineering-Recent advances and future prospects. *Comparative Immunology Microbiology and Infectious Diseases, 32*, 123-137.
Le Curieux-Belfond, O., Vandelac, L., Caron, J., & Séralini, G.-É. (2009). Factors to consider before production and commercialization of aquatic genetically modified organisms: the case of transgenic salmon. *Environmental Science & Policy, 12*, 170–189.
Logar, N., & Pollock, L.K. (2005). Transgenic fish: is a new policy framework necessary for a new technology? *Environmental Science & Policy*, *8*, 17-27.
Lutter, R., & Tucker, K. (2002). Unacknowledged Health Benefits of Genetically Modified Food: Salmon and Heart Disease Deaths. *AgBioForum, 5,* 59-34.
Maclean, N. (2003). Genetically modified fish and their effects on food quality and human health and nutrition. *Trends in Food Science & Technology, 14*, 242-252.
Melamed, P., Gong, Z., Fletcher, G., & Hew, C. L. (2002). The potential impact of modern biotechnology on fish aquaculture. *Aquaculture, 204*,: 255-269.
Melo, E.O., Canavessi, A.M.O., Franco, M.M., & Rumpf, R. (2007). Animal transgenesis: state of the art and applications. *Journal of Applied Genetics, 48*, 47-61.
Mora C., Menozzi D., Aramyan L., Valeeva N., Pakki Reddy G., Merigo A. (2011). Report on Production chain context. Deliverable D3- PEGASUS project, http://www.pegasus.wur.nl.
Newcombe, C., Newcombe, A.R. (2007), Antibody Production: Polyclonal – derived biotherapeutics. *Journal of chromatography* B, 848 (1): 2-7.
Novoselova, T., van der Lans, I.A., Meuwissen, M.P.M., & Huirne, R.B.M. (2005). Consumer acceptance of GM applications in the pork production chain: a choice modelling approach. *EAAE Congress*, August 23-27, 2005, Copenhagen, Denmark.
Novoselova, T.A., Meuwissen, M.P.M., & Huirne, R.B.M. (2007). Adoption of GM technology in livestock production chains: an integrating framework. *Trends in Food Science & Technology, 18*, 175-188.
Qin, W., & Brown, J.L. (2006). Consumer opinions about genetically engineered salmon and information effect on opinions. A qualitative approach. *Science Communication, 28*, 243-272.
Sang, H. (2003). Genetically modified livestock and poultry and their potential effects on human health and nutrition. *Trends in Food Science & Technology, 14*, 253-263.
Smith M.D., Asche F., Guttormsen A.G., Wiener J.B. (2010), Genetically modified salmon and full impact assessment. *Science*, 330, 1052-1053.
U.S. Food and Drug Administration (2010). Public hearing on the labeling of food made from the AquAdvantage Salmon. Background Document, August 2010.

van Berkel, P.H.C., Welling, M.M., Geerts, M., van Veen, H.A., Ravensbergen, B., Salaheddine, M., Pauwels, E.K. J., Pieper, F., Nuijens, J.H., & Nibbering, P.H. (2002). Large scale production of recombinant human lactoferrin in the milk of transgenic cows. *Nature Biotechnology, 20*, 484-487.
Vàzquez-Salat, N., Salter, B., Smets, G. and Houdebine L-M. (2012). The current state of GMO governance: Are we ready for GM animals? *Biotechnology Advances* xxx: xxx-xxx.
Wheeler, M.B. (2003). Production of transgenic livestock: Promise fulfilled. *Journal of Animal Science, 81*, 32-37.
Wheeler, M.B. (2007). Agricultural applications for transgenic livestock. *Trends in Biotechnology, 25*, 204-210.