# *Blunting EU regulation 1107/2009: following a regulation into a system of agricultural innovation*

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# Blunting EU Regulation 1107/2009: following a regulation into a system of agricultural innovation

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## Abstract

This paper explores the role of regulation and legislation on influencing the development and diffusion of technologies and methods of crop production. To do this, the change in pesticide registration under European Regulation 1107/2009 'Placing Plant Protection Products on the Market' was followed through the UK's agricultural system of innovation. Fieldwork included: a series of interviews conducted with scientists, agronomists and industry organisations; a programme of visiting agricultural events; as well as sending an electronic survey to British potato growers. The innovation system is noted to have made the legislation less restrictive than originally proposed. The most notable system response to the legislation is the adjustment of agrochemical company pesticide discovery strategy and their expansion into biologically derived treatments. There have also been other innovation responses: agricultural seed companies have been breeding in pathogen resistance in their cultivars; agricultural consultancies are prepared to recommend pathogen-resistant seeds; scientists are using the change as justification for adopting their solutions; the agricultural levy boards funded research into off-label pesticide uses; and producers, potato growers in particular, have been seeking advice, but not changing their growing practices.

**Keywords** Systems of Innovation · Multi-sited ethnography · Legislation · Campaigning · Pesticides · Regulation 1107/2009

## Abbreviations

| | |
|---|---|
| ADAS | Agriculture Development Advisory Services |
| AHDB | Agriculture and Horticulture Development Board |
| APPG | All Party Parliamentary Group |
| BASF | Badische Anilin- & Soda Fabrik |
| DDT | Dichloro-diphenyl-trichloroethane |
| DNA | Deoxyribonucleic acid |
| EC | European Commission |
| EU | European Union |
| GATT | General Agreement on Trade and Agriculture |
| GM | Genetically modified |
| GIS | Geographic information system |
| GPS | Global positioning system |
| HEI | Higher education institute |
| IPM | Integrated pest management |
| MNC | Multinational corporation |
| NGO | Non Governmental Organisation |
| PPE | Personal protective equipment |
| R&D | Research and development |
| SCEPTRE | Sustainable Crop and Environment Protection–Target Research for Edibles |
| SI | Systems of Innovation |
| UK | United Kingdom |
| USA | United States of America |
| WFD | Water Framework Directive |

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## Introduction

That the twenty-first century needs another agricultural revolution is well established with calls for a Doubly Green revolution (Conway 2005), low-input agriculture (Vanloqueren and Baret 2008), and sustainable agriculture in general (Pretty 2005). Some of the solutions lie in the diffusion of existing knowledge and technology and some lie in the development of new knowledge and technology. The Systems of Innovation (SI) literature (e.g. Borrás et al. 2011) gives us hope by suggesting that innovative solutions emerge through multiple channels, including policy, infrastructure, and market mechanisms (Klerkx and Leeuwis 2008). This systemic change can be intentional, such as through planned intervention, or unintentional, i.e. the unintended knock-on effects of an intervention.

This paper draws on Systems of Innovation approaches to understand how non-market factors can influence the knowledge and technologies available to the actors and networks of UK agriculture. Specifically, this research focuses on the institutional set up of the system of innovation because they "… determine the innovative performance…of national firms" (Nelson and Rosenberg 1993, p. 4). But curiously, given this interest in the institutional environment, there are few studies focusing on a particular institutional change and its influence on the system (with the exception of van Mierlo et al. 2010).

Therefore, this paper is focused on an institutional intervention into the UK's system of agricultural innovation and documents an empirical example through the case of the European Commission's (EC) Regulation 1107/2009 'Placing Plant Protection Products on the Market' (Regulation 1107/2009 herein). This paper will review Systems of Innovation thinking and then will present background on the registration of pesticides under Regulation 1107/2009. The multi-sited ethnographic fieldwork will then be described, after which the opposing views in the science-policy interface are presented and how these may have shaped the legislation. The last part of this paper presents the ways the system has responded to the legislation by discussing innovation and diffusion activities of the agrochemical industry, plant breeding, agronomists, and then will touch on how growers have responded.

## Literature on innovation systems

The basic premise of Systems of Innovation (SI) scholarship is that innovation is non-linear with multiple influences arising from entanglements of different parts of the system (Hall et al. 2003). SI scholars also cite theories of learning as significant (Johnson 2011; Lundvall 2007): as firms and individuals interact with science infrastructure or corporate reporting (as a way to interact with a regulatory framework), this has an influence on the firm, which, in part, causes the evolution of the system (Edquist and Hommen 1999). However, to describe it as a system, is not to say that it is systematically organised, but that it is *systemic* (Narula 2003); an influence on one part of the system has a ripple effect on other parts.

There is a body of sectoral innovation literature that focuses on agricultural innovation systems.[1] This literature takes inspiration from the nuanced approach of systems of innovation, in that agricultural innovation is suggested to emerge from a process of multiple interactions (Engel 1995) and involves multiple actors (Hall et al. 2003). This body of literature suggests a focus on better co-ordination to transform agriculture (e.g. Spielman et al. 2008) as it includes considerable publications on innovation intermediaries (e.g. Klerkx and Leeuwis 2008); the role of public sector extension services (Spielman et al. 2011; Klerkx et al. 2006); communication between system actors (Morriss et al. 2006); links with farmers (Rockenbauch et al. 2019; Isaac 2012) and so on. These approaches understand agricultural innovation to involve multiple actors: "It is now recognised that agricultural innovations come from multiple sources: research staff; development agencies; farmers; NGOs; private companies; entrepreneurs; and artisans" (Hall et al. 2003, p. 220).

In terms of a UK agricultural innovation system, this includes research institutes (e.g. the John Innes Centre), private sector companies (e.g. Syngenta), funding bodies (e.g. the Biosciences and Biotechnology Research Council), and government departments (e.g. the Department for Environment, Farming and Rural Affairs). Agricultural innovation systems include farmers themselves as users of products and as developers of new methods of production. These are the organisations one might try to align if trying to optimise an innovation system as seen in Gildemacher et al.'s (2009) study of Kenya, Uganda, and Ethiopia seeking increase potato production and improve farmer livelihoods.

[1] Klerkx et al. (2012) identify two agricultural innovation literatures, the Agricultural Innovation Systems literature (e.g. Hall et al. 2003) which emerged out of the SI literatures (e.g. Edquist 1997) and the Agricultural Knowledge and Innovation Systems (e.g. Engel 1995) which emerged as a critique of earlier Farming Systems Research which itself was a critique of earlier technology transfer theories. As they both emphasis the interrelated nature of the systems, they are treated interchangeably in this paper.

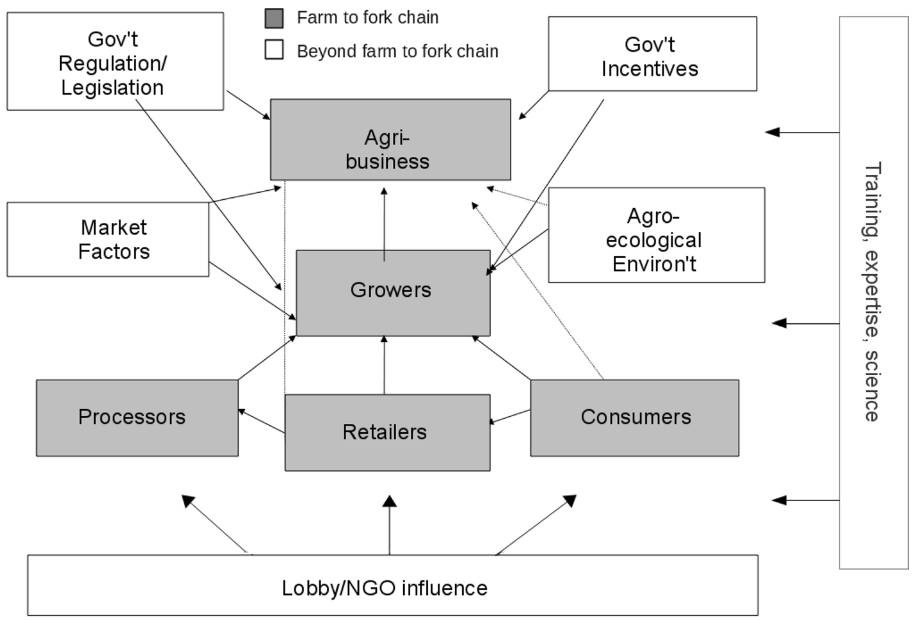


**Fig. 1** Mapping the complexity of an agricultural innovation system (*source* author)

However, the systemic approach to innovation systems (e.g. Narula 2003) casts its net wider and includes *influences* such as politics, lobbying, economic demand, the next generation of scientific expertise,[2] through to the agroecological environment and socio-technical regimes (Kuhn 1970; Dosi 1982; Vanloqueren and Baret 2008). It is an inclusive theory. The author has described these organisations and influences in detail elsewhere Payne-Gifford (2011) and mapped this complexity (see Fig. 1).

Some of these organisations are linked through sales, contracts, incentives, personal relationships, employment, regulatory requirements and agroecological constraints.

That there is a link between regulation and innovation is established in the wider innovation literature, although there is variation according to the type of regulation and as to the extent and type of innovation:

> …[T]he impacts of regulation have been assessed as rather ambivalent for innovation in general, often depending on the different types of innovation. Different types of regulations generate various impacts on innovation, and even a single specific regulation can influence innovation in various ways (Blind 2012, p. 1).

Blind's literature review on regulation and innovation identifies so-called 'social' regulation—that which seeks to correct negative externalities—as having a strong effect on innovation (as opposed to economic or institutional regulation). Although social regulation, e.g. tighter environmental restrictions, might increase the cost of compliance in the short-term, it can increase long-term gains (Blind 2012).

Kesidou and Demirel's study of the drivers of eco-innovations supports this view; although individual actors may decry the introduction of a new regulation, for environmental economists "[r]egulation is not seen as an undesirable cost-increasing factor but as a stimulator of firms' innovativeness that, in turn, would lead to a first-mover advantage in markets for eco-innovations…" (Kesidou and Demirel 2012, p. 863). Again there is variation in how firms respond to regulation, with less innovative companies adapting to regulations as a cost-saving measure and more innovative companies taking the new regulation as an opportunity to transform their business and gain access to new markets.

Particularly relevant to this paper, Ollinger and Fernandez-Cornejo's 1998 study on pesticide regulation by the USA's Environmental Protection Agency found a decreased number of products brought to market, but the encouragement of less toxic formulations. In focusing on a change in regulation and its influence of a system of innovation, the focus is not only on how firms respond; it is on how the system responds. This includes pesticide development, but also includes possible changes in agronomic practice as well as a variety of public and private agricultural goods: chemical control, biological agents, disease-resistant seeds and so on.

Moreover, when it comes to the literature on Regulation 1107/2009 none is focused on its potential to induce innovation. Researchers mention Regulation 1107/2009 as the context making their research relevant (e.g. Peruzzi et al. 2012) but these studies then go on to focus on technical matters rather than assessing whether their solution is likely to be widely adopted.

[2] Although there is demand for biological control methods (using organisms and biologically derived treatments), there is a shortage of trained entomologists to support its expansion. A junior agronomist was met during fieldwork who had applied to an agricultural consultancy for a clerical post but was taken on as a trainee agronomist because she had taken one undergraduate entomology module. The company chose to deploy that knowledge into their consultancy business rather than hire her as a receptionist.

## Background on UK pesticide use, innovation and regulation

Like many countries, agricultural pesticide use in the UK increased in the post World War Two era with the use of organochlorides such as Dichloro-diphenyl-trichloroethane (DDT) and like the rest of world, Carson's influential *Silent Spring* contributed to their phasing out (Davis 2014; Matthews 2018). In addition to banning organochlorides, this period saw the tightening of pesticide regulation, although scholars point out that these regulations were co-developed with the agrochemical companies developing new active substances (Jas 2007; Tait 2001). After the organochlorides came a new generation of organophosphates which were less damaging for the environment but more hazardous for farm workers (Tait 2001). These were then followed by the introduction of pyrethroid insecticides which were less toxic to farm operators but more toxic to aquatic life (Tait 2001) which were in turn restricted. The next generation of insecticides introduced in the 1990s, neonicotinoids, were shown to be non-lethal. However, the worldwide decline in pollinators led a new generation of scientists to investigate and demonstrate a *sub-lethal* effect on their foraging ability, one not tested for in the pesticide approvals process (Godfray et al. 2014). The use of three neonicotinoids was restricted in 2013, extended to all outdoor use in 2018 and is currently being challenged in the European courts by agrochemical company Bayer and the UK's National Farmers Union (Case 2020). The use, development and regulation of chemical plant protection products has had a close relationship with the companies creating them.

The focus of this paper, Regulation 1107/2009 'Placing Plant Protection Products on the Market', is a specific piece of legislation updating the use and registration of pesticides in the European Union. It was introduced in 2009 and came into force in 2011 (European Commission 2009a). It derives from the EU's 2006 Thematic Strategy on the Sustainable Use of Pesticides (European Commission 2006). This strategy sought to reduce risks to human, animal and environmental health by encouraging Integrated Pest Management (IPM), banning aerial spraying, increasing inspections of equipment and creating national action plans under Directive 2009/128/EC 'Sustainable Use of Pesticides' (European Commission 2009b).

Regulation 1107/2009 bans the use of certain chemicals, governs the registration of crop protection products in the EU and replaces Council Directive 91/414 with the same name. As a Regulation it acts on the individual whereas a Directive acts on the nationstate with the nationstate translating the goals of a Directive into national law (European Union 2019). Therefore, a ban on pesticide products under Regulation 1107/2009 prohibits individual farmers from using them whereas the Sustainable Use of Pesticides Directive 2009/128/EC encourages nationstates to reduce their use. There are a variety of crops potentially affected as well as uses not yet explored (e.g. ornamentals).

One of the biggest changes under the new legislation (or perhaps one of the biggest concerns of the agricultural community) is the change in the approval process from 'risk-based' to 'hazard-based' determining whether chemical pesticides will be withdrawn from use in the EU. The hazard-based approvals system under Regulation 1107/2009 refers to the hazard posed by the active substance, *in and of itself.* Whereas, a risk-based system takes this hazard *into account* and also takes into account how it used (aerial spray, granules, powder) and how it behaves in the environment (does it break down easily, does it wash away into watercourses). In practice, this means that the EU does not want to allow substances that are mutagenic, carcinogenic, toxic for reproduction, have endocrine disrupting properties, or are persistent organic or bioaccumulative pollutants (European Commission 2009a). See Table 2 in the Annex for a summary of the above restricted properties, the substances they map to, crops potentially affected and the pathogens that affect those crops.

On the side of banning based on hazard rather than risk is Dedieu and Jouzel (2015) who found that the approvals system under precursor legislation 91/414 did not, in fact, take into account how pesticides are used; although pre-approval pesticide studies may determine a product to be safe if used with appropriate personal protective equipment (PPE) when following on-label instructions, Dedieu and Jouzel found the pre-approval studies did not use on-farm observations of actual use. In the case of sodium arsenite in French vineyards, they found farm workers would potentially become contaminated when eating or smoking, a situation and type of exposure the pre-approval process did not consider (Dedieu and Jouzel 2015). The current legislation includes a requirement for member states to monitor actual usage, however, Dedieu and Jouzel still find the provision lacking. They are by no means alone in their criticism of chemical pesticides (see for example Kroma and Flora 2003; Devine and Furlong 2007; Wilson and Tisdell 2001), of the registration system that approves and defends pesticide use (e.g. Jas 2007) nor of the assumed safety of PPE in applying plant protection products (Garrigou et al. 2020).

Although the legislation states that it will not approve substances that have endocrine disrupting properties, this particular hazard criterion has proved difficult to implement. Endocrine disruption is the altering of an organism's hormonal function with established concerns for both human fertility as well as ecosystems demonstrated by Jas and Gaudillière's (2016) analysis of American and French concerns about endocrine disruptors. The difficulty in the EU comes in deciding whether *some* or *any* amount of endocrine disruption is acceptable. By 2015, defining endocrine disruption had not been resolved as it will be decided on a case by case base

(European Chemical Agency et al. 2018) when companies apply for pesticide products to be approved for use.

Seven of twenty-five at-risk substances have been withdrawn since the legislation came into force. Pesticides already in use in the EU have time-limited approvals and all substances that would be banned by this legislation are available for use until the end of their approval period. After a substance has been approved under Regulation 1107/2009 it has a standard approval period of 10 years. For substances that are carcinogens, reproductive toxins, or endocrine disruptors where is no other viable method of control, a derogation of 5 years may be granted (European Commission 2009a). There are other elements that make up this legislation (mutual recognition, comparative assessment) but they do not all need discussing to explore Regulation 1107/2009s effect on innovation.

Although the focus of this paper is on 1107/2009s potential to withdraw pesticide products, it is by no means the only policy intervention influencing innovation. The Sustainable Use Directive mentioned above encourages national development of Integrated Pest Management plans which may very well have spurred innovation in that area (see for example Bruce et al. 2017). But this is not that story. Moreover, transition to a different type of agriculture requires carrots *and* sticks.

## Methodology

This research started with an intention to conduct immersive ethnography in the research and development office of a not-yet-identified agrochemical company. Fieldwork started with an exploratory stage of visiting agricultural events and organisations documented in ethnographic fieldnotes (see Table 3 in the Annex for additional details). Four agricultural events were visited, some indoors, some outdoors (i.e. traditional agricultural shows). Tours were arranged of one large agrochemical company, one central government agency, one agricultural research institute and one agricultural university. During this exploratory phase, concern about 1107/2009 was mentioned four times, unsolicited, by an industry organisation, two agrochemical companies and one research institute suggesting its significance to the agricultural sector.

This period of gaining access unsettled the original plan of conducting ethnography in an office because agrochemical companies have research *campuses*! What's more, 1107/2009 itself acts most directly on farmers rather than public or private sector organisations. Entering the field with an open mind led to the realisation that 1107/2009 may have an influence on the public sector as well as on agricultural sectors outside the agrochemical sector. Therefore, the potential research site was broadened from a not-yet-approached agrochemical company to conceptualise the field-site as the abstract notion of an innovation system. The focus on 1107/209 remained as a way to provide a focal point and a way of making a study of the system manageable.

Taking inspiration from multi-sited ethnographic approaches (Appadurai 1988; Marcus 1995; Falzon 2009; Coleman and von Hellermann 2011), 1107/2009 was followed into the UK's system of agricultural innovation through attending more agricultural events (also in Table 3 in the Annex), document analysis and a series of audio-recorded semi-structured interviews. Seven more events were attended, all involving science and agronomy presentations; three were 'mainstream' agricultural science events, i.e. on advances in using pesticides, fertilisers, machinery and high-performing seeds on monocrop plantations, although the audiences were largely not growers. Two subsequent events were growers' events, one of which was an organic growers' conference. One event was a series of presentations by a government regulatory agency on 1107/2009 itself and the last event was a biological control conference.

A series of semi-structured interviews was conducted with informants that include: agrochemical companies, public sector agricultural research organisations, regulatory bodies, lobby organisations, farmers, agricultural consultants and so on. Twenty-nine people were approached and eighteen interviews were conducted usually starting with a free-form discussion of the legislation, what it meant for their organisation, specific crops that were affected and options for pathogen control in a post-1107/2009 world. See Table 4 in the Annex for additional details on interviewees.

A third phase was implemented to develop a case study specifically on potato cultivation for two reasons: 1. The change in regulation was threatening mancozeb, one of the major fungicidal agents used to protect potatoes against late blight (*phytophthora infestans)*, a major pathogen of potatoes; 2. The previous phases had included more non-growers than growers, the actual focus of the legislation and the users (or not) of agricultural innovations. To overcome barriers of geography, a survey was implemented, although one that made widespread use of free-text boxes in addition to quantifiable questions. The main focus of the survey was whether potato growers would shift away from chemical fungicides if mancozeb was withdrawn to biological and/or practice-based ways of controlling late blight. They indicated they would likely not change for reasons of market and environmental constraint. However, the focus of this paper is on actual changes already made (as opposed to theoretical actions not yet taken) which was found in the qualitative free-text responses.

Therefore, this paper builds a case study on Regulation 1107/2009 and uses interviews, ethnographic fieldnotes, official documents as well as some qualitative responses to the electronic survey sent to British potato growers. Qualitative analysis using AtlasTi resulted in two main themes: An unexpected inductive theme on the negotiation and disagreements of the science-policy process; and a deductive theme looking for views on and responses to the change in legislation.

**Table 1** Opposition and support for Regulation 1107/2009 found during fieldwork

| | Sentiment | Informants echoing sentiment |
|---|---|---|
| Opposition | "Regulation not based on science" | Lawyer<br>Industry Organisation<br>Agri scientist A<br>Agri consultant F |
| | "Regulation may increase pathogen resistance" | Agri consultant A, C, and D<br>Agrochemical company A, B, C<br>Agri scientist A<br>Industry Organisation<br>Regulator |
| | "No impact assessment carried out" | Industry Organisation<br>Agrochemical company B<br>Regulator |
| Support | Reduce health risks/ Protect health | Anti-pesticide campaigner A, B, and C<br>Toxicologist |
| | Reduce environmental risk | European Commission document |

## Us and them and 1107/2009

This section explores how tensions in the legislative process influenced the formation of legislation and how this in turn influenced the environment in which innovation occurs. Even before analysis of fieldwork data that related specifically to Regulation 1107/2009, there was a general oppositional attitude in the field, an 'us and them', with battlelines drawn between incompatible types of agriculture. Box 1 offers an excerpt of a presentation by an ex-agrochemical employee where he compared intensive agriculture to sustainable agriculture and said, "neither work".

### Box 1: Presentation excerpt by former agrochemical company employee dichotomising agricultures

| Sustainable agriculture | Intensive agriculture |
|---|---|
| Low input | High input |
| Organic | High tech |
| Small farms | Huge farms |
| [Fieldnote excerpt of presentation, sustainable intensification workshop] | |

This is not to say that there is no agreement that industrial agriculture needs to change: "organic does some good things for soil" [Fieldnote excerpt, industry workshop]. However, that agreement made, there is a reluctance to cross sides and change allegiances.

While this dichotomy of mainstream versus sustainable agriculture played out generally in the fieldwork, it is also reflected more specifically in the discourses and debates about Regulation 1107/2009. See Table 1 for a selection of pros and cons of the legislation encountered during fieldwork. That there is more representation by those opposing the legislation is not significant; rather it is a result of sample selection; more interviewees representative of mainstream agriculture were approached for views on Regulation 1107/2009 and because it is a threat to mainstream agriculture, most of these interviewees were understandably opposed to the legislation. But this paper does not wish to speculate or dwell on the pros and cons of the legislation, rather it seeks to demonstrate the sides of the science battle that are represented: informants seemed to be for or against the legislation with little middle ground to agree on.

Let us unpick some of the oppositional assertions from both sides by first having a close reading of the official minutes of the 2008 meeting of the All-Party Parliamentary Group (APPG) on Science & Technology in Agriculture convened to discuss the development of Regulation 1107/2009 (APPG 2008). If we examine the following extracts of the minutes from the 2008 meeting, we can see how some of the opposition is potentially exaggerated to serve as ammunition for and against the legislation. This meeting took place before the legislation was finalised in 2009 and before it came into force in 2011.

First, we see an industry representative warning against Regulation 1107/2009 because the cut-off criteria may automatically remove products from use in the EU, with an estimated range of 15–85% depending on the version of the legislation implemented:

Opposed speaker: "[The] switch from the current risk-based assessments to the use of hazard-based 'cut-off' criteria…would automatically remove a significant number of products currently approved and with a track record of safe use. Based on an impact assessment carried out by the UK's Pesticides Safety Directorate, the potential loss of currently approved pesticide products would range from 15% under the Commission's original proposals to as much as 85% under First Reading amendments agreed by the European Parliament." [Minute 2 of APPG meeting, industry representative, italics added for emphasis (APPG 2008)]

However, once contributions from the floor are included (i.e. people not invited to table papers), an anti-pesticide campaigner casts doubt on the 85% and 15% withdrawal scenario mentioned by the first speaker.

Supportive speaker: "[An anti-pesticide campaigner] described the presentations as scaremongering, failing to mention the safeguards built in to the legislation which would allow application of essential use derogations for five years where no effective alternative was available. According to the Commission, just 23 active substances would be lost. Some UK food retailers had already adopted hazard-based criteria in their own standards without affecting supply volumes or prices. [Contributions from the floor of APPG meeting, anti-pesticide campaigner, italics added for emphasis (APPG 2008)]

The campaigner raises the 'essential use' derogation built into the legislation, whereby if there is no other way to control a pest in a crop, that substance will be allowed but reviewed after 5 years, in case a different method of control has become commercially viable in that time.

On the other side of the battleline, those that support Regulation 1107/2009, there are comments in support of it, that are countered by those that do not. For the campaigner comments about the legislation supporting public and environmental health there are commentators on the other side of that battleline likewise casting doubt on the environmentalists' assertions. For the campaigner concerned about the effects of pesticides on foetal and infant development, there was an industry representative not convinced the proposed legislation would actually improve public health.

Concerned about endocrine disrupting pesticides: [Campaigner] declared an interest as a longstanding campaigner against pesticide products, particularly those associated with endocrine disruption. Her concern was that evidence showed effects on the foetus at very low levels, yet no pesticide had gone through testing for such effects despite the claims of rigorous controls. [APPG minute 4, campaigner, italics added for emphasis (APPG 2008)]

Less concerned about endocrine disrupting pesticides: [Industry representative] agreed that concerns over potential health effects such as endocrine disruption were extremely important. However, the lack of transparency behind the Commission's proposal meant there was no certainty or clarity over the definition of what the cut-off criteria were, how they would apply, or how they would improve public health. [APPG minute 4, industry rep, italics added for emphasis (APPG 2008)]

When one pays attention to the fact there are battle-lines drawn, that there are vested interests in winning the battle, we can see that perhaps some of the above opposition (and indeed support) is hyperbole, or if not hyperbole, at least discourse, those stories that circulate in a community and are 'true' to that community. Neither is untrue in the absolute sense, but rather that truth comes to be produced by those communities: "…in trying to make sense of the situation under study, researchers often find that the people with whom they work have drawn on a relatively small number of shared discourses in various combinations" (Cook and Crang 1995, p. 12). This is not to say that informants actually lie[3] but that they *believe* their discourses and belief in a story influences action.

If this research is about the factors that influence innovation, why are the tensions, the he-said-she-said and the mud-slinging being discussed at length? It is because these disagreements influence the formulation of the legislation which then in turn influences innovation and technological change. Although this paper is focused on the implications of the legislation as it came into force in 2011, it did not spring into existence fully-formed. A draft of the legislation would have been made available for comment and subsequent drafts issued in the period before 2009. Both sides of the science battle will have made their case and used statements like those above as ammunition in the consultation process which may have reformulated the final legislation.

In the case of Regulation 1107/2009 this has indeed happened and is evidenced not just by the minutes of the Science and Technology All-Party meeting. There are other negotiation processes as well. In an interview with a former industry organisation representative, he recounted the steps he took to rally opposition to the legislation by the food industry and by the British government:

Interviewing referring to Regulation 1107/2009: "The regulatory issue was there when I arrived [in post] in

[3] Well, maybe sometimes they do, but this more to be expected if researching illegal activities or marginal behaviour.

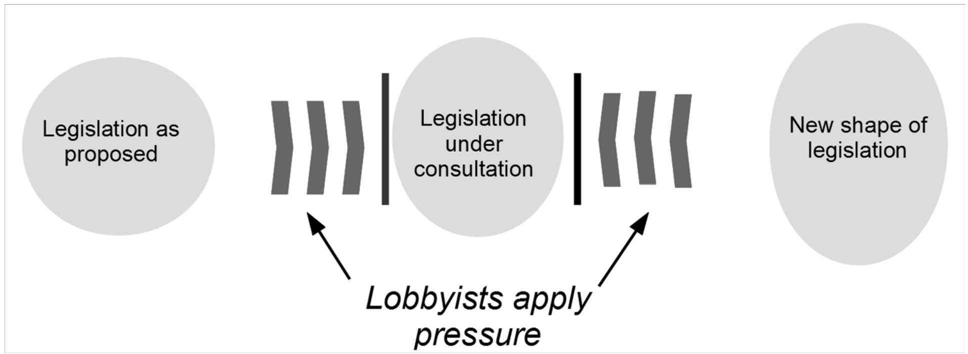


**Fig. 2** Conceptualising the influence of lobbying on legislation (*source* author)

2008….So one of the first things I did was to line up everyone from the farmers union…to the food and drink industry…and I knew many of these organisations prior to arriving on the job so I spoke to all the heads of the organisations…. I said we have a few pieces of legislation emerging in Brussels which is going to be very damaging to UK food production and industry at a time when prices are rising very rapidly and we need to really get that out to the Prime Minister and get that out to all the ministers." [Interview excerpt, ex-industry representative]

This was a co-ordinated response by an industry organisation to rally farming representatives, food representatives, agrochemical companies and other industry representatives to express their concern about the legislation to the Prime Minister's office. The UK government then expressed this concern to Brussels. Newspaper coverage at the time shows evidence of this industry response to the legislation, although not all led by the same industry organisation mentioned above. For example, *The Daily Mail,* a popular newspaper, reported in 2008 that the legislation would ban dozens of pesticides after the consultancy Agriculture Development Advisory Services (ADAS) assessed the potential influence of the legislation (Daily Mail 2008). The ADAS analysis was also reported specifically to different farming sectors: *Farming UK*, a farming newspaper, reported ADAS delivering their results to the annual conference of the potato levy body as a call for potato growers to stay up to date on their pesticide options (Farming UK 2009).

As to whether there was scope to influence the legislation in 2008 when it was under consultation, the industry interviewee's response was:

"What we managed to do was blunt it."

By 'blunting' the legislation, making it less restrictive than first proposed, this allows certain chemical substances and therefore pesticide products to continue to be used in the EU. Not only are certain products made available for use, those actors that develop and refine them will horizon scan to see what types of products are still going to be in use in 5, 10, 15 years time. In this way, the regulatory system is a precursor state, encouraging and discouraging innovation to occur in certain ways. If that precursor state has been moulded into a certain shape by lobbying, then the innovation that is encouraged or discouraged will fit that new shape (see Fig. 2).

Using Fig. 2 as a metaphor, if the legislation in question starts off 'circular' but ends up 'oval-shaped' due to lobbying by campaigners, then the end-points under that legislation will be 'oval' as well. In the case of the 'blunting' of Regulation 1107/2009, with fewer active substances at risk of withdrawal, this allows not only the continued use of those substances in the shorter-term, but also the development of products containing those substances, as well as products with similar chemical characteristics; if no endocrine disrupting chemicals are allowed in EU crop production, then research and development into other substances with any endocrine disrupting properties will also be affected. Conversely, if some level of endocrine disruption is considered acceptable, then research into products with this characteristic are still worthwhile in the European context. In short, research, innovation, diffusion cannot occur in certain ways if those ways are banned—or even if they *may* be banned.

## Conceptualising campaigning

If we refer back to Fig. 1, lobbyists and campaigners are included as one of the influences affecting the system. Innovation systems scholars acknowledge lobbying and campaigning to influence the system under scrutiny although many have not explored this in detail: Klerkx et al.'s (2006) case study on the attempted adoption of a nutrient management system sought clear division of actors in this process which included lobbying organisations, although did not explore further; Markard and Truffer (2008) note that campaigning and lobbying by companies and professional organisations are involved in progressing fuel cell technology although do elaborate and do not focus on legislative issues; Randelli and Rocchi (2017) acknowledge that consumer organisations act as lobbyists influencing policy and investment (in cycling, occupational safety) and argue for including consumers in an innovation systems approach but do not explicitly go into detail on when or how.

This is not to say that social scientists have not studied the role of lobbying and campaigning on agri-food policy, innovation or governance structures. Lang (1999) described "a loose collection of public health professionals, specialists, and a new generation of Non Governmental Organizations" as an effective lobby in introducing food safety legislation in the UK, among other achievements. Campaigners are noted to have influenced international governance structures such as the General Agreement on Trade and Agriculture (GATT), the precursor to the World Trade Organisation (Glover 2002) as well as company divestment from agricultural portfolios (Newell 2003). Brasier's analysis of the USA's 1996 Farm Bill focused specifically on the role of campaigners in its formulation (Brasier 2002).

Hermans et al. call this lobbying institutional entrepreneurship (2013) where a group of actors separate from inventors and innovation brokers seek to change institutions and leverage resources to do so: "An institutional entrepreneur therefore also works to change the broader context so that the innovation has a widespread appeal and impact (Hermans et al. 2013, p. 119). Bloomfield and Doolin, in discussing the development of transgenic cows in New Zealand, describe "the intersections between the official governance process…*and the public debate, protest and legal challenges to the research* (Bloomfield and Doolin 2011, p. 73, italics added for emphasis)." Campaigners for and against transgenic cattle helped slow the research programme and made consumers wary of transgenic foodstuffs.

Therefore, lobbying, campaigning and dissent or "the bargaining process between those representing government and the players" (Torfing 2010) can influence both formal—e.g. public consultations—and informal governing. When Walls et al. describe the role of NGOs in the governance of risk, it is part of a *formal* governance process: a "[p]rocedural role of governance rest[ing] on guaranteeing the participation of stakeholders" (Walls et al. 2005, p. 636) where NGOs "promote their vision of a better world" (Walls et al. 2005, p. 637). However, the influencing of a former prime minister described by the industry representative is not a formal part of the making of Regulation 1107/2009 yet still managed "to blunt it". Although the Science and Technology committee meeting discussed earlier *was* a formal part of the political process, they are not a formal part of the law-making process yet still exert influence on the law-makers. Even though not acting directly on companies or research institutes (although sometimes they do through direct action) campaigners exert influence on the background environment in which they operate, meaning some activities do not operate at all in the EU.

## Innovation responses to Regulation 1107/2009

After the informal re-shaping of the legislation by the lobbyists for and against this legislation, what is the sector's view on whether innovation is enabled or constrained? The general view of interviewees was that Regulation 1107/2009 was a barrier to innovation, expressed in this interview excerpt:

> Industry representative: "Companies are uncertain about developing technology where they have to invest significant levels of money and they have very long pipelines to get it to market. It takes 10 or 15 years to get one of these products approved and if you have go through 300 separate tests on average for EU by law and you have a 10 year period patent but if you get to a point where you have invested all that and you find there has been a tightening of the legislation then that's a disaster!" [Interview excerpt, ex-industry representative]

The above speaker is referring to the chemical discovery and patenting process that the agrochemical companies go through to bring a new pesticide to market. A change in legislation may make that process longer, more unpredictable and even more expensive than it already is. In his view, this is a barrier to innovation. However, if we now expand analysis away from the industry's negative opinion of the legislation, we see that Regulation 1107/2009 has had a number of different responses by different parts of the system. So yes, it might be a barrier in some ways but let us look at the variety of responses before concluding too easily.

### Agrochemical industry responses

The above comment suggests that Regulation 1107/2009 is a barrier to innovation for the agrochemical companies in terms of chemical discovery. However, they have not been complacent in the face of this legislation and have responded to the legislation with new pesticide formulations and investment in alternative methods of control.

The first possible response is for the agrochemical industry to develop products without substances at risk. The two agrochemical companies interviewed did this by introducing mancozeb-free fungicides, although not as a co-ordinated response. Mancozeb is at risk because it has endocrine disrupting properties. In the below example, one of the companies stated it had developed a mancozeb-free product as a response to the legislation.

> Fieldnote excerpt: "In response to question of whether Regulation 1107/2009 is driving [their] planning, they replied 'Yes, is driving medium-term planning. For R&D guys is longer-term target, most multi-sites are threatened.' They also said, but didn't write down while conducting interview, that they are developing mancozeb-free formulations." [Fieldnote excerpt of an interview with agrochemical company]

That company commented that the threat of Regulation 1107/2009 is driving their longer-term response by driving their research into replacements for multi-sited pesticides—ones that disrupt more than one physiological process—as many of this class of product are threatened.

Agrochemical companies have also been engaging in strategies that make them less dependent on their chemical portfolios in the EU market. One of the major ways is that the large agrochemical companies are noted to have invested in biocontrol, that is, niche companies that specialise in biological methods for controlling pests and pathogens. This is a serendipitous trend rather than co-ordinated action by the agrochemical companies. Although there may be multiple reasons for them to expand into this niche area, such as the 2009/128/EC Sustainable Use of Pesticides Directive (European Commission 2009b), informants attributed this expansion to the threat of Regulation 1107/2009 withdrawing chemicals. Indeed, the topic came up a number of times in the field, both solicited and unsolicited by different actors in the innovation system. See Box 2 for a selection of mentions of agrochemical company expansion into biocontrol.

**Box 2: Mentions of agrochemical investment in biological control during fieldwork**

1. "It's driving biocontrol, Bayer, Syngenta, BASF have recently invested." [Fieldnote excerpt, ex-agrochemical employee]
2. "And they actually have programmes. Where they [agrochemical companies] have integrated pest management biological companies, they're buying all those." [Interview excerpt, agricultural scientist]
3. "Acquisition of Becker-Underwood mentioned a lot here." [Fieldnote excerpt, biocontrol conference]
4. "We don't intend on being taken over" [Fieldnote excerpt, biocontrol company employee referencing big companies buying other biocontrol companies, biocontrol conference]

In the above box on expansion into biological control, we see that the agrochemical sector has noted it about themselves and about their competitors (Example 1). Likewise, agricultural scientists (Example 2) have noticed the trend as well. It was also a hot topic at a conference of biocontrol specialists (Examples 3–4), particularly the acquisition of biocontrol company Becker-Underwood by German chemical company Badische Anilin- & Soda Fabrik (BASF). If the suite of chemicals is restricted, there is little choice but for the agrochemical companies to explore other options. They do not expect it to replace the chemical options for control, but neither does the biocontrol sector: "It's not the only solution," a biocontrol expert said [Fieldnote excerpt, biocontrol employee, biocontrol conference].

## Plant breeding

The expertise of breeders is also being put to use in the response to Regulation 1107/2009. In addition to chemical plant protection products, another way of maximising a crop is through breeding. Size of tuber, seed pod, stalk, as well as shape, flavour, colour and more can be selected by breeders. It also possible to breed resistance to pests and pathogens into plant cultivars. Regulation 1107/2009 is attributed by the following junior agronomist to be helping drive investment into breeding resistant cultivars:

> Junior agronomist: "I think that in terms of managing things going forward a lot more effort is going into breeding. If you look at the big companies, how they are shifting their R&D funds into plant breeding, is a sign how things are changing with that." [Interview excerpt, junior agronomist].

In the case of potatoes, companies are requesting and breeders are putting effort into breeding resistance against late blight (as well as other targets such as size and shape).

> Interviewer: "If late blight is a [breeding] target for you, do you think having mancozeb at risk puts pressure on?"
> Breeder: "Puts pressure on the companies I work with. That's why they say we want blight resistance. We have two ways of tackling that. We use what [genetic stock] is available and some of our own [genetic stock]. Some colleagues are working with wild species. Some are also working with Sainsbury's Laboratories on a GM approach." [Interview excerpt, potato breeder].

This breeder attributes the threat of legislation as one of the reasons that companies and breeders such as himself include blight resistance on their list of traits to select for. His statement above also suggests that the legislation drives the exploitation of wild genetic resources as well as the opportunities that lie in transgenic approaches. As with agrochemical company acquisition of biocontrol companies, seed companies investing in pathogen resistance is convergence of company strategy rather than a co-ordinated response.

## Agronomists

Agronomists both help develop innovations by trialling them as well as help in their diffusion by recommending new products and methods to their clients. Triazole fungicides, widely used on cereals, may be withdrawn for the same reason as mancozeb because they may be endocrine disruptors. The threat of the withdrawal of these fungicides was discussed with an agronomist interviewee and the options for control if they are withdrawn:

> Agronomist: "We'd have to look at other ways of controlling and if that meant using other chemical treatments, you would have to go for that. But as things are withdrawn you would have to look at the whole picture more and use everything in your power to control disease. So, choosing a top yielding variety may not be a priority. A grower's priority may be what is the best variety against [septoria tritici]. Going forward, different varieties are more and more important again." [Interview excerpt, junior agronomist]

For the above agronomist, her response indicates a preference for the remaining fungicides if triazoles are withdrawn. But if the context in the EU changes she would then consider more resistant varieties of wheat over the top-yielding ones. Therefore, agronomists are important sources of growing strategy and become a conduit for the diffusion of growing products and methods.

## Scientists

There are a variety of scientists working to provide solutions for the agricultural sector: chemists, biologists, geneticists, ecologists, toxicologists, and the list goes on. There are roughly two types of responses: the shorter-term responding directly to the threat of the legislation and longer-term with solutions that have yet to break into the vacuum.

In the short term, there are agricultural scientists assessing and exploring the options for managing without specific chemicals. For the agricultural scientist below, their recommended strategy is similar to the agronomists above; alternative fungicides combined with varietal resistance (even though the agronomist above is discussing wheat and the scientist below is discussing potatoes).

> Interviewer: "Legislation can force changes in innovation…"
> Agricultural scientist: "Generally what works best to choose as many strategies as you can so as many fungicides and combine them with varietal resistance." [Interview excerpt, agricultural scientist]

In the example above, the interviewee is speaking hypothetically because fungicide mancozeb has not been withdrawn yet. However, the threat of its withdrawal was causing actual action as well as hypothetical. A research institute has phased out mancozeb in preparation for its potential withdrawal to prove that it is possible:

> Research institute: "We moved to no mancozeb products as we are a research institute and needed to show that there were effective alternatives." [Survey respondent, agricultural scientist]

If the definition of endocrine disruption is set such that mancozeb is withdrawn under Regulation 1107/2009, there are scientists that have been preparing for its withdrawal that will be able to provide options for growing as effectively as possible.

There were also long-term examples of action such as using the withdrawal of chemicals to justify the need for cutting edge agricultural technologies. Take for example the poster depicted in Fig. 3 on weed mapping and precision farming:

In the box, the first bullet point answering the why of automated weed mapping reads: "Loss of herbicides due to EU Regulations and the Water Framework Directive."[4] The authors of this poster are arguing that a restricted pool of chemical pesticides necessitates more precise use of those that remain. Precision agriculture—the use of GPS and GIS (Global Positioning Systems and Geographic Information Systems) to precisely apply inputs—is not a new technique but has been slow to diffuse (a potato grower interviewee has been using these methods for 20+ years). The authors of the above poster are using the change in legislation to facilitate the movement of these methods into the chemical crop protection vacuum created by Regulation 1107/2009.

Does this sort of positioning count as innovation though? Making arguments that "My research is important, pesticides are being withdrawn across Europe" will be utilised when funding allocations for these types of research are discussed and negotiated. Having the funding to conduct this research is an obvious precursor to *then* conducting research. Latour, the grandfather of the ethnography of science, might agree. In *Science in Action*, his 1987 monograph on following scientists, he spends some time describing engineers inside-doing-science and managers outside-gaining-resources. This division of labour is seen in the case of Tom West trying to develop a new computer, the *Eclipse MV/8000* (on which pictures of the 3D shape of DNA were later taken in 1985):

> West is always moving around from headquarters to marketing firms and from there to electronic fairs.

[4] The Water Framework Directive (WFD) is another piece of EU legislation that is frequently mentioned as a driver of agricultural change in Europe. The WFD seeks to restore European waters to a state similar to pristine, undisturbed water, phrased in the legislation as "good ecological status'" which necessarily precludes the detection of pesticide chemicals in these waters (European Commission 2000).

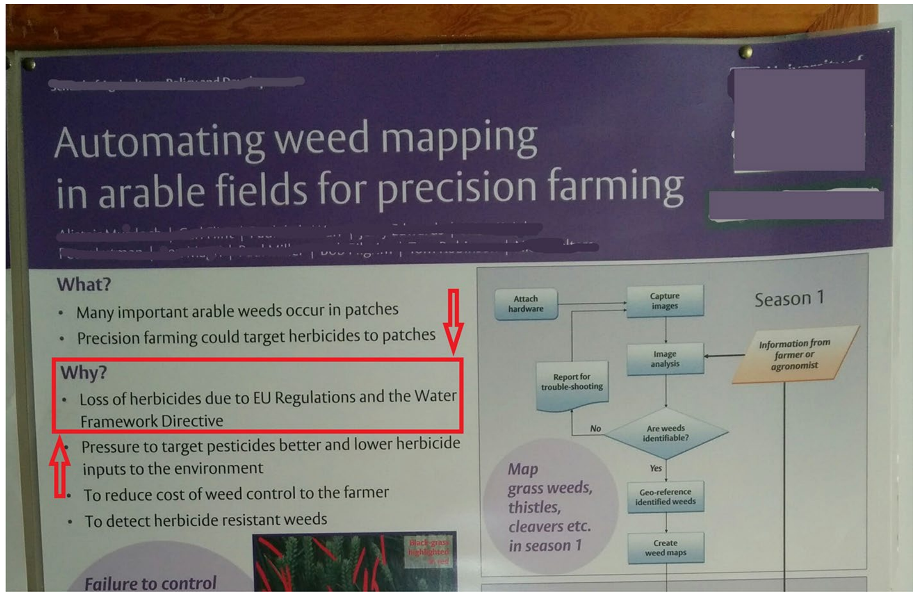


**Fig. 3** Photo of science poster (unpublished) taken during fieldwork on automated weed mapping with box highlighting loss of herbicides due to EU Regulations

> While he is away, the microkids [the engineers in the lab] are working like devils, completely insulated from any economic or political hurdle (Latour 1987, p. 155).

West is outside the laboratories gaining resources by visiting marketing firms and electronic fairs so that his engineers can work away on technical things and not be encumbered with politics. West's schmoozing enables the engineers to keep engineering. As in the case of the *Eclipse MV/8000,* technological change in the agricultural sector is also not accidental or neutral. There are managers outside gaining resources so their own "microkids" can keep "working like devils". In the same way that campaigning on the legislation influences precursor conditions, this influences a future precursor state in terms of funding allocations. One cannot push forward the boundaries of agricultural science nor influence diffusion of agricultural technology without the resources to do so. The managers, as well as scientists attending industry events, will also have brought back to the laboratories messages about 1107/2009 and a potentially reducing chemical suite. However, it is unlikely messages about 1107/2009 will have made scientists substantially change their activities due to the long timescales of scientific discovery. It is more likely these scientists are making their research more relevant by referencing a current social issue.

## A cross-industry consortium

Another response to the threat of the legislation was Sustainable Crop and Environment Protection–Target Research for Edibles (SCEPTRE). This was a cross-industry consortium funded by the agricultural levy board, the Agriculture and Horticulture Development Board (AHDB). The project explored innovation in minor crop protection with the suite of chemicals that remain after Regulation 1107/2009 by testing 92 chemical pesticides and 67 biopesticides. Of the consortium, the agrochemical company interviewed above noted:

> Agrochemical company: "[We're] part of it, is a good project, joint funding working together. Brings innovation to minor crops area. Legislation drives project. Lost actives due to legislation. Loss of herbicides major issue for veg growers. Lost seven actives in veg." [Fieldnote excerpt, agrochemical company]

Minor crops often have less investment devoted to their protection because the return on investment is lower than major crops such as potatoes or cereals. As a result, minor crop growers (often vegetables and speciality ornamentals) will seek off-label approvals to use products developed for the major crops on their minor crops. As a result, the agricultural and horticultural sectors responded by looking for alternative uses for the chemicals that remain as well exploring a number of potentially under-utilised biopesticides. The SCEPTRE project brought together 24 partners that span those included in this paper: big agrochemical companies, smaller agricultural consultancies, scientists, levy boards as well as nurseries, biocontrol companies and retailers. Bringing these partners together as a co-ordinated response to 1107/2009 and using existing chemicals in a new way is an innovation, just not of the product-innovation type (Fagerberg 2005; Heertje 1988). The project's most important finding is that new products have been found to fill gaps in horticultural crop protection arising from the change in legislation (ADAS 2015).

## Potato growers

This legislation acts directly on growers, in that it is growers that would be breaking the law if they used a banned pesticide. But is there more to a response than simply not using a banned chemical? As suggested in the interview excerpts above there are a range of growing options that might enter a vacuum created by a withdrawn substance. Also, the chemicals that are withdrawn do not disappear overnight, they have a registration period that is not renewed so any withdrawal has a few years of lead-in.

The survey sent to potato growers about their growing practices revealed that some have been reducing their use of the chemicals at risk, but most have not changed their growing practices. When asked if they had changed their growing practices as a result of the legislation, more than 80% responded 'No', they had not because "it ain't been banned yet!" [Survey respondent, potato grower].

However, these growers are not necessarily complacent with their heads in the sand. They are *consciously* doing little until required. Firstly, they are thinking through the options for growing potatoes without mancozeb by seeking appropriate technical advice:

> Potato grower: "[N]ot yet but speaking to agronomist about alternatives for late blight control." [Survey Respondent, potato grower]

The growing strategies mentioned above of the consultants, of the scientists, are put into action when these agronomists recommend them to growers looking for options.

Those actors that utilise contract growers, such as processors, are also biding their time thinking through how they would adapt to the legislation. For example, the processor below would consider eliminating susceptible potato varieties from their portfolio:

> Interviewer: "If mancozeb is withdrawn, how will that affect [your] growing strategy?"
> Processor: "It will significantly affect what the growers can use, may make some of the varieties [of potatoes] much more risky to grow. Many varieties are not particularly blight resistant, eliminate them from the [growing] portfolios. I am sure if there is a market for potatoes…." [Interview excerpt, potato processor].

Given that there is a market for potatoes if mancozeb is withdrawn, that UK consumers still want to eat potatoes, the above processor will consider alternative varieties to fill the vacuum created if mancozeb is withdrawn.

So, potato growers and those that employ them have not largely changed their growing practice as a result of the legislation but are seeking advice on how to adapt. Although the above grower examples all relate to potato cultivation, it is likely that other growers of crops with chemical pesticides at risk are doing the same: seeking technical advice from their agronomist and thinking through their growing practice.

These may be examples of preparing for and anticipating change, similar to the reasons Lamine (2011) found in French arable farmers' transition to IPM. In Lamine's case of transitioning to IPM, multiple factors (economics, ecology, health and more) converged to push her participants to explore IPM approaches, some more robustly than others. However, the survey data received does not indicate that potato growers (who are usually arable farmers in their rotations) experience enough converging factors to substantially change their growing practice for the following reasons: many grow on contract and their clients request varieties of potatoes that are not pathogen-resistant; the late blight pathogen is fairly virulent and farmers do not want to risk crop failure; at the time of writing there was no commercially available biological control alternative although a number of investigations are underway (Yao et al. 2016; De Vrieze et al. 2018). The only alternative is organic cultivation, which uses copper sulphate prophylactically and resistant cultivars. As their clients do not contract them to grow resistant cultivars, this does not seem to be enough to push many UK potato growers to radically change their growing practice. However, the focus of this paper is on the potential for 1107/2009 to make space for alternative methods of production. Having made space, this does not guarantee these alternatives will be adopted by farmers.

## Winners and losers?

This is not to say that the examples above were the only examples or the only types of science hoping to break into the vacuum of 1107/2009: there were geneticists hoping 1 day their field trials would not be torn out of the group by anti-GM campaigners; there was a discussion with a doctoral researcher working on integrated pest management in horticultural greenhouses; there was a regulatory liaison officer who had completed a PhD on biocontrol that said "I'm pushing for it", for more field trials testing biological control; and there were ecologists giving presentations to organic growers about timing the planting of arable crops to manage herbivorous beetles.

Which innovations, whether products or practices, are adopted does not ultimately depend on which are optimal. Social studies of science, particularly those with a historical view (e.g. Latour and Woolgar 1979) often demonstrate innovations that could have been more than adequate but not adopted due to social or political factors were. I.e., if a lone inventor creates a brilliant gadget, there are conditions that influence whether a company will be interested in developing a proof of concept further and whether potential users of that gadget *actually want to use* it. For example, Latour (1987) tells the story of the failure of a domestic computer chip industry to develop in Brazil. Or, more relevant to agri-food concerns, Harvey (2004) tells the story of the failure of the genetically modified tomato in the 1990s, due to a business failure on the part of Calgene to establish a consumer market for this product. Systems of Innovation scholarship helps to explain, conceptualise, and diagram those social factors affecting the invention, adoption or diffusion of innovations.

## Summary

This paper has reconfirmed the literature that suggests regulation contributes to innovation. However, that literature does not give a nuanced account of how debates *about* regulation influence the final formulation of the regulation nor how that debate itself is part of the informal shaping of innovation. Therefore, this paper also provides an empirical example of how lobbying can influence a system of innovation which the extant literature theoretically acknowledges but has not provided concrete examples. In the case of Regulation 1107/2009, the informal process of its negotiation resulted in a number of iterations of the legislation with the final version less restrictive than originally proposed. As a result, fewer active substances are likely to be withdrawn which not only allows products containing them to continue to be used, it also allows development of similar substances. So on the one hand, this legislation might be constraining innovation in the UK by making the chemical discovery process more difficult and expensive, but on the other hand, the role of lobbyists in the legislative process reduced this effect, made it "blunt".

Regulation 1107/2009 has directly influenced the agrochemical sector by forcing them to develop mancozeb-free fungicides. The legislation has also indirectly influenced the agrochemical sector with their acquisition of biocontrol companies and expertise. These companies have analysed the shape of the future European agricultural landscape and seen that it is not only chemical products that will be used to produce our food, it also includes biologically derived products as well. For them to maintain a presence in the EU market, they must do this or become irrelevant.

Regulation 1107/2009 is also putting pressure on plant breeders with pathogen resistance being a target to breed for as opposed to high yield. Those that provide advice (agronomists and scientists) have been looking at the various options for continuing to cultivate and often recommend alternative chemicals combined with resistant cultivars. Those scientists working to provide long-term solutions have been using the legislation as an opportunity to offer their solutions to fill the vacuum. The levy body, AHDB, also funded and coordinated a cross-industry consortium that identified new uses for existing chemical and biological pesticides.

Regulation 1107/2009 has done all this by threatening to withdraw chemical plant protection products. From the 85% withdrawal scenario mentioned earlier, to date, only seven of the twenty-five substances listed in Table 2 in the Annex have been withdrawn. Granted, more may be withdrawn if the definition of endocrine disruption is resolved, but nonetheless, this environmental and health and safety legislation has helped spur investment in biological control and influenced the precursor states to the adoption of resistant varieties as well as other methods and products. So, although the system shaped the legislation to be less restrictive, the system still hedged its bets with back-up plans by making space for alternative methods and technologies.

Although some growers have been thinking about what to do and making some small adjustments to their growing practices, in the case of potato growers, they have not yet responded to the legislation. However, it is largely not the growers that develop innovations, but because they are bound up in an innovation system their response (or future response) has an effect due to the interconnected nature of the system. The *potential* for diffusion causes yet another precursor state that the suppliers of innovations may take into account when considering developing a new chemical formulation or breeding a new cultivar. Not only this, when innovations are introduced into the system, through their use, growers may feed back into the system to improve the innovations, blurring the line between innovation and diffusion.

From an instrumental point of view, if we wish to intervene in the system so as to transition to a different type of agriculture, it is prudent to understand what end-users of an innovation want and need and what barriers there are to change. If a grower's hands are tied because other parts of the system lock them in to certain ways of growing, understanding their needs may allow additional intervention into the system. Although Regulation 1107/2009 acts directly on growers and the withdrawal of chemical compounds potentially creates a vacuum into which other methods of control may enter, there may be other parts of this system acting more strongly on growers. Therefore, further analysis on grower barriers is required.

The UK's departure from the EU does not undo the effects of Regulation 1107/2009 that have already occurred. The so-called 'damage' is done. Also once departed, this may create the need to review Regulation 1107/2009 and could result in new legislation being proposed which would trigger the to-ing and fro-ing legislative process all over again.

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## Compliance with ethical standards

**Ethical approval** This research was conducted under ethical approval given by the University of Reading. Informed consent was sought from individuals participating in the study.

## Annex

See Tables 2, 3 and 4.

**Table 2** Substances at risk: substances most likely to be withdrawn by Regulation 1107/2009, crops affected and pest and pathogens controlled

| Property | Substance (f = fungicide; i = insecticide; h = herbicide) | Crops | Pests, pathogens and weeds |
|---|---|---|---|
| Mutagen | Carbendazim (f) | Wheat, oats, barley | *Septoria*, *fusarium* |
| Carcinogens | Flufenoxuron[a] (i) | Apples, brassicas | Phytophagous mites |
| Reproductive toxin | Bitertanol[a] (f) | Tomatoes, apples, | Scab, powder mildew, rusts |
| | Carbendazim (f) | Wheat, oats, barley | *Septoria, fusarium* |
| | Dinocap[a] (f) | Grapes, apples, peppers | Powdery mildew |
| | Flusilazole[a] (f) | Apples, plums, sugarbeet | Scab, powdery mildew |
| | Flumioxazine (h) | Peanuts, soybeans | Pondweed, algae |
| | Glufosinate (h) | Canola, potatoes | Grass, broad-leaved weeds |
| | Linuron (h) | Carrots, celery, beans | Grass, broad-leaved weeds |
| Endocrine disruptor | Bifenthrin (i) | Lettuce, cabbage, grapes | Sucking foliar pests |
| | Thiacloprid (i) | Apples, lettuce, peppers | Sucking and chewing pests |
| | Bitertanol[a] (f) | Tomatoes, apples | Scab, powder mildew, rusts |
| | Carbendazim (f) | Wheat, oats, barley | *Septoria, fusarium* |
| | Cyproconazole (f) | Cereals, field crops | *Septoria,* rusts |
| | Epoxiconazole (f) | Wheat, sugar beet | Ascomycetes |
| | Fenbuconazole (f) | Cereals, vines, stone fruit | Powdery mildew, black rot |
| | Flusilazole[a] (f) | Apples, plums, sugarbeet | Scab, powdery mildew |
| | Iprodione (f) | Strawberries, lettuce | Botrytis, Minilia |
| | Mancozeb (f) | Potatoes, melons, lettuce | Blights, mildews and scabs |
| | Maneb (f) | Potatoes, field crops | Blight, leaf spot, rust |
| | Metconazole (f) | Canola, barley, oats | Alternaria, rusts, fusarium |
| | Tebuconazole (f) | Cereals, field crops | Smut and bunt diseases |
| | Amitrole (h) | Veg, fruit, cereals | Grass, broad-leaved weeds |
| | Ioxynil[a] (h) | Onions, carrots, cereals | Broad-leaved weeds |
| | Linuron (h) | Carrots, beans, celery | Grass, broad-leaved weeds |
| | Molinate[a] (h) | Rice, other crops | Grass, broad-leaved weeds |
| | Tralkoxydim (h) | Cereals | Grass |
| Persistent organic pollutant | None | | |
| Persistent bioaccumulative toxin | Bifenthrin (i) | Lettuce, cabbage, grapes | Sucking foliar pests |
| | Esfenvalerate (i) | Barley, fruit, veg | Coleoptera, diptera |
| | Lufenuron (i) | Grapes, tomatoes | Biting and sucking insects |
| | Pendimethalin (h) | Carrots, brassicas, grains | Grass, broad-leaved weeds |
| Very persistent and very bioaccumulative | Bifenthrin (i) | Lettuce, cabbage, grapes | Sucking foliar pests |
| | Quinoxyfen (f) | Cereals | Erysiphe graminis, powdery mildew |

*Source* based on Pesticide Safety Directorate (2008) and University of Hertfordshire n.d

[a]Identified substances that have since been withdrawn

**Table 3** Table of fieldwork visits

| Summary of Phase 1 visits | |
|---|---|
| Events and visits | Location |
| "Financing Agri-innovation" Full day of talks about commercialisation | London, UK |
| "Cereals" Outdoor agricultural tradeshow focused on cereals production | Lincolnshire, UK |
| "Farm Open Day" Outdoor tour and explanation of test-plots and test varieties | Cambridgeshire, UK |
| Visit to large agrochemical company | Not available[a] |
| Visit to central government agency | Not available[a] |
| Visit to publicly funded agricultural research institute | Not available[a] |
| Visit to agricultural college | Not available[a] |
| Summary of Phase 2 events | |
| Event | Location |
| "Sustainable Intensification" Society of Chemical Industry Workshop | Southern England |
| "CropWorld" Agricultural Tradeshow | London |
| "Are Pesticides Dangerous?" CafeScientifique Public Talk | Southern England |
| Organic Growers Conference | Midlands |
| Annual Potato Growers Conference | East Anglia |
| "Efficacy Under 1107/2009 Conference" | Yorkshire |
| Annual IPM and Biocontrol Manufacturer's Conference | Lincolnshire |

[a] As there are only a few each of agrochemical companies, government agencies, agricultural research institutes and agricultural colleges, revealing their location also reveals their identity

**Table 4** Interviewees and topics covered

| Actor | Agri-business | Grower | Pro-cessor | Retailer | Agri con-sult-ant | Reg-ula-tor | Gov advice/ enforce-ment | Public agri research | Charita-ble agri research | Levy org | HEI | Indus-try org | Opinion 1107/2009 | Mod-ern, indus-trial agri | Alter-native farm-ing | Alt con-trol gen-eral | Chemi-cal control | Bio-logi-cal con-trol | Genetic control | Cul-tural control |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| PhD researcher | | x | | x | | | | | | | x | | | | | x | | x | | |
| MNC agro-chem 1 | x | x | | | | | | | | x | | | x | x | | | x | | | |
| MNC agro-chem 2 | x | | | | | | | | | | | | x | x | | | x | | | |
| Charitable research | | x | | x | | | | | x | | x | | | | | x | | | x | |
| Consultant | x | x | | | x | | | | | | x | | x | x | x | | x | | | |
| Industry org | x | x | | | | | | | | | | x | x | x | | | x | | x | |
| Regulator | x | x | | | | x | x | | | | | | x | x | | | x | | | |
| Grower and entrepre-neur | | x | | | | | | | | | | | x | x | x | | x | | | |
| Farm employee | | x | x | | | | | | | | | | | x | | | x | | | |
| HEI 1 | | | | | | | | x | | | x | | | x | | | | x | | |
| HEI 2 | | x | | | x | | | x | | | x | | x | x | | x | | | | x |
| Public research org 1 | | x | x | x | | | | x | | | | | | | | | | | | x |
| Public research org 2 | | | | | | | | x | | | | | x | x | | | | | x | |
| Industry org 1 | | x | x | x | | | x | | | x | | | x | x | | | | | | x |
| Industry org 2 | | | | | | | | | | x | | | x | x | | | x | | x | x |
| Organic stand-ards and grower | | x | | | | | | | x | | | | | | x | x | | | | |
| Junior con-sultant | | | | | x | | | | | | | | x | | | | | | x | |
| Packer | | x | x | x | | | | | | | | | x | x | x | | | | | |
| MNC agro-chem 3 | x | | | | | | | | | | | | x | x | | | x | | | |

**Table 4** (continued)

| Actor | Agri-business | Grower | Processor | Retailer | Agri consultant | Regulator | Gov advice/enforcement | Public agri research | Charitable agri research | Levy org | HEI | Industry org | Opinion 1107/2009 | Modern, industrial agri | Alternative farming | Alt control general | Chemical control | Biological control | Genetic control | Cultural control |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Total | 8 | 13 | 4 | 5 | 3 | 1 | 3 | 4 | 3 | 3 | 7 | 1 | 14 | 18 | 6 | 4 | 12 | 2 | 7 | 3 |

## References


Agriculture Development Advisory Services (ADAS). 2015. *Grower Summary: Sustainable Crop and Environment Protection–Target Research for Edibles (SCEPTRE), All Years (2010–2015).* Wolverhampton. https://projectblue.blob.core.windows.net/media/Default/Research%20Papers/Horticulture/CP%2077_GS_Final_All%20years_0.pdf. Accessed 16 September 2020.

All Party Parliamentary Group (APPG) on Science and Technology in Agriculture. 2008. *Impact of EU Pesticide Approval Plans: Notes of Meeting 4.30–6.00pm, Tuesday 28 October, Thatcher Room, Portcullis House.* Westminster. http://www.appg-agscience.org.uk/linkedfiles/28%20OCT%20MTG%20NOTES.doc. Accessed 16 September 2020.

Appadurai, A. 1988. Commodities and the politics of value. In *The social life of things: Commodities in cultural perspective*, ed. A. Appadurai. Cambridge: Cambridge University Press.

Blind, Knut. 2012. *The impact of regulation on innovation. Compendium of evidence on the effectiveness of innovation policy intervention*. NESTA and Manchester Institute of Innovation Research. https://media.nesta.org.uk/documents/the_impact_of_regulation_on_innovation.pdf. Accessed 16 September 2020.

Bloomfield, B.P., and B. Doolin. 2011. Imagination and technoscientific innovations: Governance of transgenic cows in New Zealand. *Social Studies of Science* 41: 59–83. https://doi.org/10.1177/0306312710385372.

Borrás, S., J. Fagerberg, and C. Edquist. 2011. Introduction to special issue on learning, innovation systems and policy in honour of Bengt-Åke Lundvall. *Science and Public Policy* 38: 666–668. https://doi.org/10.3152/030234211X13070021633404.

Brasier, K.J. 2002. Ideology and discourse: Characterizations of the 1996 Farm Bill by agricultural interest groups. *Agriculture and Human Values* 19 (3): 239–253. https://doi.org/10.1023/A:1019913920983.

Bruce, T.J.A., L.E. Smart, A.N.E. Birch, V.C. Blok, K. MacKenzie, E. Guerrieri, P. Cascone, E. Luna, and J. Ton. 2017. Prospects for plant defence activators and biocontrol in IPM—Concepts and lessons learnt so far. *Crop Protection* 97: 128–134. https://doi.org/10.1016/j.cropro.2016.10.003.

Case, P. 2020. Bayer and NFU battling to overturn neonicotinoids ban. *Farmers Weekly,* 4 June, online. https://www.fwi.co.uk/arable/crop-management/bayer-and-nfu-battling-to-overturn-neonicotinoids-ban. Accessed 16 September 2020.

Coleman, S., and P. von Hellermann, eds. 2011. *Multi-sited ethnography: Problems and possibilities in the translocation of research methods*. New York: Routledge.

Conway, G. 2005. The doubly green revolution. In *Earthscan reader in sustainable agriculture*, ed. J. Pretty. London and Sterling, VA: Earthscan.

Cook, I., and M. Crang. 1995. *Doing ethnographies*. Norwich: Geobooks.

Daily Mail Reporter. 2008. Plans to ban dozens of pesticides will 'lead to food shortages and send prices rising further'. *Daily Mail,* 2 July. https://www.dailymail.co.uk/news/article-1031265/Plans-ban-dozens-pesticides-lead-food-shortages-send-prices-rising-further.html. Accessed 16 September 2020.

Davis, F.R. 2014. *Banned: A history of pesticides and the science of toxicology*. New Haven and London: Yale University Press.

Dedieu, F. and J.-N. Jouzel. 2015. How to ignore what one already knows: Domesticating uncomfortable knowledge about pesticide poisoning of farmers in France. *Revue française de sociologie* 56 (1): 105–133. Translated by A. Jacobs-Colas. https://doi.org/10.3917/rfs.561.0105.

Devine, G.J., and M.J. Furlong. 2007. Insecticide use: Contexts and ecological consequences. *Agriculture and Human Values* 24 (3): 281–306. https://doi.org/10.1007/s10460-007-9067-z.

De Vrieze, M., F. Germanier, N. Vuille, and L. Weisskopf. 2018. Combining different potato-associated *Pseudomonas* strains for improved biocontrol of *Phytophthora infestans*. *Frontiers in Microbiology*. https://doi.org/10.3389/fmicb.2018.02573.

Dosi, G. 1982. Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change. *Research Policy* 11 (3): 147–162. https://doi.org/10.1016/0048-7333(82)90016-6.

Edquist, C. 1997. Economic infrastructures and innovation systems. In *Systems of innovation: Technologies, institutions, and organizations*, ed. C. Edquist and K. Smith. London: Pinter.

Edquist, C., and L. Hommen. 1999. Systems of innovation: Theory and policy for the demand side. *Technology in Society* 21: 63–79. https://doi.org/10.1016/S0160-791X(98)00037-2.

Engel, P.G.H. 1995. *Facilitating innovation: An action-oriented approach and participatory methodology to improve innovative social practice in agriculture*. Wageningen: Wageningen University.

European Chemical Agency (ECHA) and European Food Safety Authority (EFSA) with the technical support of the Joint Research Centre (JRC), N. Andersson, M. Arena, D. Auteri, S. Barmaz, E. Grignard, A. Kienzler, P. Lepper, A.M. Lostia, S. Munn, J.M. Parra Morte, F. Pellizzato, J. Tarazona, A. Terron, and S. Van der Linden. 2018. Guidance for the identification of endocrine disruptors in the context of Regulations (EU) No 528/2012 and (EC) No 1107/2009. *EFSA Journal* 16: e05311. https://doi.org/10.2903/j.efsa.2018.5311.

European Commission. 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. *Official Journal of the European Communities* L 327 (43): 1–73.

European Commission. 2006. *Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions—A thematic strategy on the sustainable use of pesticides* {COM(2006) 373 final} {SEC(2006) 894} {SEC(2006) 895} {SEC(2006) 914} /* COM/2006/0372 final */. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52006DC0372. Accessed 17 September 2020.

European Commission. 2009a. Regulation (EC) No 1107/2009 of the European Parliament and of the Council of 21 October 2009 concerning the placing of plant protection products on the market and repealing Council Directives 79/117/EEC and 91/414/EEC. *Official Journal of the European Union* L 309 (52): 1–50.

European Commission. 2009b. Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides. *Official Journal of the European Union* L 309 (52): 71–86.

European Union. 2019. *Regulations, Directives and other acts*. https://europa.eu/european-union/eu-law/legal-acts_en. Accessed 17 September 2020.

Fagerberg, J. 2005. Innovation: A guide to the literature. In *The Oxford handbook of innovation*, ed. J. Fagerberg. Oxford: Oxford University Press.

Falzon, M.-A., ed. 2009. *Multi-sited ethnography: Theory, praxis and locality in contemporary research*. Farnham: Ashgate Publishing Ltd.

Farming UK Team. 2009. Potato Council delivers response to spray loss threat. *Farming UK,* 28 July. https://www.farminguk.com/news/potato-council-delivers-response-to-spray-loss-threat_16721.html. Accessed 17 September 2020.

Garrigou, A., C. Laurent, A. Berthet, C. Colosio, N. Jas, V. Daubas-Letourneux, J.-M. Jackson Filho, J.-N. Jouzel, O. Samuel, I. Baldi, P. Lebailly, L. Galey, F. Goutille, and N. Judon. 2020. Critical review of the role of PPE in the prevention of risks related to agricultural pesticide use. *Safety Science* 123: 104527. https://doi.org/10.1016/j.ssci.2019.104527.

Gildemacher, P.R., W. Kaguongo, O. Ortiz, A. Tesfaye, G. Woldegiorgis, W.W. Wagoire, R. Kakuhenzire, P.M. Kinyae, M. Nyongesa, P.C. Struik, and C. Leeuwis. 2009. Improving potato production in Kenya, Uganda and Ethiopia: A system diagnosis. *Potato Research* 52 (2): 173–205. https://doi.org/10.1007/s11540-009-9127-4.

Glover, D. 2002. Transnational corporate science and regulation of agricultural biotechnology. *Economic and Political Weekly* 37 (27): 2734–2740.

Godfray, H.C.J., T. Blacquière, L.M. Field, R.S. Hails, G. Petrokofsky, S.G. Potts, N.E. Raine, A.J. Vanbergen, and A.R. McLean. 2014. A restatement of the natural science evidence base concerning neonicotinoid insecticides and insect pollinators. *Proceedings of the Royal Society B: Biological Sciences* 281 (1786): 20140558. https://doi.org/10.1098/rspb.2014.0558.

Hall, A., V.R. Sulaiman, N. Clark, and B. Yoganand. 2003. From measuring impact to learning institutional lessons: An innovation systems perspective on improving the management of international agricultural research. *Agricultural Systems* 78: 213–241. https://doi.org/10.1016/S0308-521X(03)00127-6.

Harvey, M. 2004. The appearance and disappearance of the GM tomato: Innovation strategy, market formation and the shaping of demand. In *Agribusiness & society: Corporate responses to environmentalism, market opportunities and public regulation*, ed. K. Jansen and S. Vellema. London: Zed Books.

Heertje, A. 1988. Schumpeter and technical change. In *Evolutionary economics: Applications of Schumpeter's ideas*, ed. H. Hanusch. Cambridge: Cambridge University Press.

Hermans, F., M. Stuiver, P.J. Beers, and K. Kok. 2013. The distribution of roles and functions for upscaling and outscaling innovations in agricultural innovation systems. *Agricultural Systems* 115: 117–128. https://doi.org/10.1016/j.agsy.2012.09.006.

Isaac, M.E. 2012. Agricultural information exchange and organizational ties: The effect of network topology on managing agrodiversity. *Agricultural Systems* 109: 9–15. https://doi.org/10.1016/j.agsy.2012.01.011.

Jas, N. 2007. Public Health and Pesticide Regulation in France before and after silent spring. *History and Technology* 23 (4): 369–388. https://doi.org/10.1080/07341510701527435.

Jas, N., and J.P. Gaudillière. 2016. Les perturbateurs endocriniens en France. Une autre trajectoire. *Sciences Sociales et Sante* 34 (3): 19–46. https://doi.org/10.1684/sss.20160302.

Johnson, B. 2011. From user–producer relations to the learning economy. *Science and Public Policy* 38: 703–711. https://doi.org/10.3152/030234211X13070021633288.

Kesidou, E., and P. Demirel. 2012. On the drivers of eco-innovations: Empirical evidence from the UK. *Research Policy* 41: 862–870. https://doi.org/10.1016/j.respol.2012.01.005.

Klerkx, L., and C. Leeuwis. 2008. Balancing multiple interests: Embedding innovation intermediation in the agricultural knowledge infrastructure. *Technovation* 28 (6): 364–378. https://doi.org/10.1016/j.technovation.2007.05.005.

Klerkx, L., K. de Grip, and C. Leeuwis. 2006. Hands off but strings attached: The contradictions of policy-induced demand-driven agricultural extension. *Agriculture and Human Values* 23 (2): 189–204. https://doi.org/10.1007/s10460-005-6106-5.

Klerkx, L., B. van Mierlo, and C. Leeuwis. 2012. Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions. In *Farming systems research into the 21st century:*

*The new dynamic*, ed. I. Darnhofer, D. Gibbon, and B. Dedieu. Dordrecht: Springer.
Kroma, M.M., and C Butler Flora. 2003. Greening pesticides: A historical analysis of the social construction of farm chemical advertisements. *Agriculture and Human Values* 20 (1): 21–35. https://doi.org/10.1023/A:1022408506244.
Kuhn, T. 1970. *The structure of scientific revolutions*, 2nd ed. London: University of Chicago Press.
Lamine, C. 2011. Transition pathways towards a robust ecologization of agriculture and the need for system redesign. Cases from organic farming and IPM. *Journal of Rural Studies* 27 (2): 209–219. https://doi.org/10.1016/J.JRURSTUD.2011.02.001.
Lang, T. 1999. The complexities of globalization: The UK as a case study of tensions within the food system and the challenge to food policy. *Agriculture and Human Values* 16 (2): 169. https://doi.org/10.1023/A:1007542605470.
Latour, B. 1987. *Science in action*. Milton Keynes: Open University Press.
Latour, B., and S. Woolgar. 1979. *Laboratory life: The construction of scientific facts*. Princeton, N.J: Princeton University Press.
Lundvall, B.-Å. 2007. National innovation systems—Analytical concept and development tool. *Industry and Innovation* 14 (1): 95–119. https://doi.org/10.1080/13662710601130863.
Marcus, G.E. 1995. Ethnography in/of the World System: The emergence of multi-sited ethnography. *Annual Review of Anthropology* 24: 95–117.
Markard, J., and B. Truffer. 2008. Actor-oriented analysis of innovation systems: Exploring micro–meso level linkages in the case of stationary fuel cells. *Technology Analysis & Strategic Management* 20 (4): 443–464. https://doi.org/10.1080/09537320802141429.
Matthews, G.A. 2018. *A history of pesticides*. Wallingford: CABI. https://doi.org/10.1079/9781786394873.0000
Morriss, S., C. Massey, R. Flett, F. Alpass, and F. Sligo. 2006. Mediating technological learning in agricultural innovation systems. *Agricultural Systems* 89 (1): 26–46. https://doi.org/10.1016/j.agsy.2005.08.002.
Narula, Rajneesh. 2003. Understanding the Growth of International R&D Alliances. In *Multinational enterprises, innovative strategies and Systems of Innovation*, ed. J. Cantwell. Cheltenham: Edward Elgar.
Nelson, R., and N. Rosenberg. 1993. Chap 1: Technical innovation and national systems. In *National innovation systems: A comparative analysis*, ed. R. Nelson and N. Rosenberg. New York, Oxford: Oxford University Press.
Newell, P. 2003. Globalization and the governance of biotechnology. *Global Environmental Politics* 3 (2): 56–71. https://doi.org/10.1162/152638003322068218.
Ollinger, M., and J. Fernandez-Cornejo. 1998. Innovation and regulation in the pesticide industry. *Agricultural and Resource Economics Review* 27: 15–27.
Payne-Gifford, S. 2011. A conceptual framework of agribusiness product development: Carrot, stick or both? In *Proceedings of ECIE 2011: The 6th European Conference on Entrepreneurship and Innovation*.
Peruzzi, A., C. Frasconi, L. Martelloni, M. Fontanelli, and M. Raffaelli. 2012. Use of steam and exo thermic compounds for weed seedbank control in bands (band-steaming). In *International Conference of Agricultural Engineering CIGR-AgEng2012*.
Pesticide Safety Directorate (PSD). 2008. *Assessment of the impact on crop protection in the UK of the 'cut-off criteria' and substitution provisions in the proposed Regulation of the European Parliament and of the Council concerning the placing of plant protection products in the market.* http://data.parliament.uk/DepositedPapers/Files/DEP2008-1717/DEP2008-1717.pdf. Accessed 17 September 2020.
Pretty, J., ed. 2005. *Earthscan reader in sustainable agriculture*. London and Sterling, VA: Earthscan.
Randelli, F., and B. Rocchi. 2017. Analysing the role of consumers within technological innovation systems: The case of alternative food networks. *Environmental Innovation and Societal Transitions* 25: 94–106. https://doi.org/10.1016/j.eist.2017.01.001.
Rockenbauch, T., P. Sakdapolrak, and H. Sterly. 2019. Do translocal networks matter for agricultural innovation? A case study on advice sharing in small-scale farming communities in Northeast Thailand. *Agriculture and Human Values* 36 (4): 685–702. https://doi.org/10.1007/s10460-019-09935-0.
Spielman, D.J., J. Ekboir, D. Kristin, and C.M.O. Ochieng. 2008. An innovation systems perspective on strengthening agricultural education and training in sub-Saharan Africa. *Agricultural Systems* 98 (1): 1–9. https://doi.org/10.1016/j.agsy.2008.03.004.
Spielman, D.J., K. Davis, M. Negash, and G. Ayele. 2011. Rural innovation systems and networks: Findings from a study of Ethiopian smallholders. *Agriculture and Human Values* 28 (2): 195–212. https://doi.org/10.1007/s10460-010-9273-y.
Tait, J. 2001. Pesticide regulation, product innovation and public attitudes. *Journal of Environmental Monitoring* 3: 64–69. https://doi.org/10.1039/B105803G.
Torfing, J. 2010. Governance. In *Encyclopedia of political theory*, ed. M. Bevir. Thousand Oaks, CA: Sage Publications.
University of Hertfordshire. No date. PPDB: Pesticide Properties Database. https://sitem.herts.ac.uk/aeru/ppdb/en/. Accessed 17 September 2020.
Vanloqueren, G., and P.V. Baret. 2008. Why are ecological, low-input, multi-resistant wheat cultivars slow to develop commercially? A Belgian agricultural 'lock-in' case study. *Ecological economics* 66 (2): 436–446.
van Mierlo, B., C. Leeuwis, R. Smits, and R.K. Woolthuis. 2010. Learning towards system innovation: Evaluating a systemic instrument. *Technological Forecasting and Social Change* 77: 318–334. https://doi.org/10.1016/j.techfore.2009.08.004.
Walls, J., T. O'Riordan, T. Horlick-Jones, and J. Niewöhner. 2005. The meta-governance of risk and new technologies: GM crops and mobile telephones. *Journal of Risk Research* 8: 635–661. https://doi.org/10.1080/13669870500101200.
Wilson, C., and C. Tisdell. 2001. Why farmers continue to use pesticides despite environmental, health and sustainability costs. *Ecological Economics* 39 (3): 449–462. https://doi.org/10.1016/S0921-8009(01)00238-5.
Yao, Y., Y. Li, Z. Chen, B. Zheng, L. Zhang, B. Niu, J. Meng, A. Li, J. Zhang, and Q. Wang. 2016. Biological control of potato late blight using isolates of Trichoderma. *American Journal of Potato Research* 93 (1): 33–42. https://doi.org/10.1007/s12230-015-9475-3.

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