A perfect match? The co-creation of the tomato and beneficial insects markets

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Title

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Abstract

This article analyses interdependencies in the agri-food system; it focuses on the relationships between agri-supply and agricultural production markets, based on a case study of the emergence and development of an insect market for the protection of crops in the tomato production sector. It mobilizes the sociology of market agencements, thus making it possible to highlight the human and non-human actors, the devices and the market work that link these two markets. From the perspective of Callon's economic sociology, we first analyse the market agencements that gave rise to the beneficial insect market; we then show that it is in part determined by the dynamics of the tomato market, where its customers are to be found. The “market work” in each of the two markets makes their articulation possible. These inter-relationships build an integrated system, from agro-processing through to the commercialisation of tomatoes.

Keywords

Market co-creation, beneficial insects, market agencements, market work, tomato, supply market

1. Introduction

The recent introduction of public policies to reduce the use of phytosanitary products, distributors' demands for no pesticide residues on fruit and vegetables and the interest being shown in organic agriculture have led to improvements in biological control techniques such as using beneficial insects to protect crops. These techniques were the focus of considerable attention at the end of the 20th century (van Lenteren and Woets, 1988; van Lenteren, 2000), but were then gradually forgotten (Warner and Getz, 2008; Bale et al., 2008). In tomato production, beneficial insects are now widely used by both conventional growers and organic producers to pollinate or to fight other insects that destroy crops (van Lenteren et al., 2018). Unlike biological control through preservation, which consists in stimulating populations of insects that are already present, the development of so-called inundative biological control involves the introduction of massive quantities of insects into the crops (Altieri et al., 1997). Although it is theoretically possible to produce and, above all, preserve insects on agricultural holdings, producers purchase the vast majority of their beneficial insects from specialist suppliers. Studies conducted by entomologists specialising in biological control have already underlined the centrality of the beneficial insect market. For example, van Lenteren has highlighted the fact that the development of integrated pest management can be undermined by an unstable insect supply or by the insufficient quality of those that are sold (van Lenteren 2003; 2012). Moreover, insects are generally sold along with a consultancy service that helps to encourage changes in farming practices. Yet in the field of research on the transition towards a more environmentally friendly agricultural system, agricultural supply has been to a large extent overlooked, in particular the emergence and structuring of a beneficial insect market.

Our article aims to fill this gap in the analysis of the role of agri-supply in the transformation of agricultural practices. Our case study concerns the production of fresh tomatoes, where integrated pest management has existed for over thirty years and is now widespread. The duration of this crop protection method makes it an ideal observation point from which to understand this mutual development. We highlight how the beneficial insect market and the tomato market evolve together, in symbiosis, i.e. feeding one another. For this analysis, we refer to the sociology of market agencements developed by Callon (Callon, 1998; Callon et al. 2002; Çalışkan and Callon, 2010). From this perspective, a market is made up not only of the goods (in this case insects) and services (in this case agricultural advice) exchanged, but also of the sellers, buyers, market devices and market professionals (Callon, 2016). Over recent years, this theoretical framework has been used to analyse the agri-food system, particularly with a view to reconstructing the emergence of different types of innovation (Miele and Lever, 2013; Buller and Roe, 2014; Hebert 2014; Le Velly and Dufeu, 2016; Henry, 2017; Wang, 2018). Indeed, because the sociology of market agencements was inspired by science and technology studies, it pays particular attention to the process of commodification, i.e. the creation of markets rather than markets which already exist (Çalışkan and Callon, 2010). It is therefore well suited to the analysis of the emergence of the beneficial insect market. Our paper will test this theoretical framework not only to analyse this insect market, but also to understand the tomato market, where its main customers are located. We therefore seek to highlight the conditions under which market agencements can act on two markets at the same time.

Our article therefore falls within the field of research that studies the (re)definition of relationships within the agri-food system (Rossi et al., 2019). In a recent book, Julie Guthman (2019) highlights what strawberry production in California owes to the fumigation of soil with pesticides, and with methyl bromide in particular. She thus

sketches a system of human and non-human actors, a "more than human assemblage", from research laboratories and agri-supplies to commercialisation (cooling, packing, shipping facilities) via the land, its bioclimatic conditions, the producers and their employees. All of these entities are inseparably linked by the treatment of the soil with fungicide products. In our case study, it is not pesticides but insects that define the contours of the tomato market. Their widespread use since the late 1990s has led to the development of an original production and commercialization system that is based on their presence and their work. In particular, we owe them the diversification of varieties and the implementation of economic strategies based on "zero pesticides" labels. In return, the tomato market encourages the development of the pollinators and beneficial insects market: huge numbers of tomato producers have remained loyal customers. They help not only to assess the quality of the insects, but also to improve them, by bringing their skills as users to the co-construction of the products. These mutual relations create inter-dependencies between the fresh tomato market and the beneficial insect market. In the final section, we show that this co-creation is the result of the "market work" (Cochoy and Dubuisson-Quellier, 2013; Mason et al, 2017) of two types of intermediary, the tomato market's producer organizations (POs) and the insect market's technical sales representatives: most importantly, they help to define the products traded on the market. For these two categories, the work of market mediation is not limited to a single market but articulates two distinct markets.

2. Material and methods

This research is based on semi-directive interviews with actors from the tomato and insect pest control sectors. Our fieldwork on the tomato sector took place in 2018 and 2019, among producers who belong to the AOPn – the Association d'Organisations de

Producteurs nationale “Tomates et Concombres de France” (French association of producer organisations - Tomatoes and Cucumbers). The AOPn has 23 members, including 2 independent producers. They are responsible for approximately 50% of France’s tomato production, 90% of which is grown in greenhouses. The authors met growers, technicians from farms and producer organisations (PO), and quality managers from the POs. For our fieldwork on the insect pest control sector, in 2019 we interviewed sellers and technical sales representatives from the three main beneficial insects groups[1] in direct relationship with producers, and a small number of intermediaries, such as agricultural engineers working for generalist procurement cooperatives (which sell not only beneficial insects but also fertilizers, yellow signs for greenhouses and all types of agricultural equipment). This series of interviews was facilitated by the fact that one of the authors had already carried out an initial study among these tomato producers in 2010. The purpose of that previous study had been to understand how distributors influence the introduction of cultural practices that are more environmentally friendly (*Anon*, 2014). A total of over seventy semi-directive interviews with durations of between 1 and 3 hours were conducted, recorded and transcribed. These interviews focused on the supply and use of insects, on the relationships between buyers and sellers and on day-to-day biological control practices. They were analysed using manual methods, generating 8 categories of analysis: insects (ontology and production), insect quality, logistics, packaging, farmer-seller relationship, economic competition (tomato producers and insect producers), PO strategies and seller strategies. On farms, interviews were usually followed by a visit to the greenhouses to see where and how the insects were placed.

[1] The biocontrol market remains small: in France in 2017 it stood at €140m i.e. just 5% of the plant protection market, albeit with strong growth (+25%). Macroorganisms represent 14% of biocontrol-related business (Data from the International Biocontrol Manufacturers Association - IBMA). In Brittany there is one strawberry and tomato producer organisation that has its own insect farm. All other producer organisations buy their insects from the 5 companies present in the market, based in France, Holland, Belgium, Spain and Italy.

3. Theoretical framework

The aim of our article is to analyse the emergence and development of an insect market for the pollination and protection of crops in the tomato production sector, along with the consequences for tomato production and commercialisation practices. Our analysis is part of the field of research built around the concept of market agencement (Çalışkan and Callon, 2010; Callon, 2016; Cochoy et al, 2016), which seeks to understand how new markets are formed. Rather than considering them as an interface between pre-existing supply and demand, this sociology considers "the mass of operations necessary for markets to form" (Le Velly and Moraine, 2020), and the use of market devices in particular (Muniesa et al., 2007), to gradually adjust supply and demand. For example, Onyas and Ryan have shown that the availability of pulpers is essential for the development of an organic coffee sector in Uganda (Onyas and Ryan, 2015) and Wang has described the socio-technical assembly (of agricultural engineers, farmers, exporters, calculation agencies, economic models, cooling infrastructures, worms and kinship links) that gave rise to the export of lettuce from Taiwan to Japan (Wang, 2018). This approach makes it possible to highlight the heterogeneous nature and great diversity of the markets thus created.

In order to properly complete this work, the sociology of market agencements is based on the Actor-Network Theory, from which it borrows a utility for "market devices" (Muniesa et al. 2007) and for human and non-human entities in the analysis of commodification, thus making it possible to broaden the description of the processes observed. In the agri-food system, the market devices include standards and labels, for example for animal welfare or organic agriculture (Miele 2011; Miele and Lever 2013; Fouilleux and Loconto 2017), packaging (Cochoy, 2004; Hawkins, 2012; Phillips 2016), the organisation of sales outlets

(Cochoy, 2007; Hagberg et al., 2020), or even price lists (Henry, 2017), etc. Also, non-human entities can be natural entities, such as insects. Agricultural products, whether plant or animal, differ from other products (Buller and Roe, 2014): they are generally seasonal, perishable, and characterized by greater variability than standardized industrial products (Anon, 2013; Freidberg, 2009). In our work, we come across numerous human and natural entities: this agricultural supply market is not only influenced by tomato producers taken individually as customers who buy insects, by insect sellers and their consultancy services, but also by the actions and decisions of tomato producer organisations considered as economic actors (Hardie and MacKenzie, 2007). Moreover, the traded product (i.e. the living insects) is important. Like other farmed products, its commodification is based on the appropriation of a natural resource and relies on specific material characteristics. The problems caused by the nature of insects, their quality, their effectiveness and any related services require adjustments between the actors involved in qualifying the products and in structuring the market (Callon, Meadel, and Rabeharisoa, 2002; Cochoy and Dubuisson-Quellier, 2013; Vatin 2013).

This theoretical framework also offers a dynamic view of the markets. Firstly, it analyses market construction rather than stabilised markets; secondly, it does not consider a pre-existing and fixed supply and demand, but instead sociotechnical agencements that are constantly evolving and whose various components impact one another (Cochoy et al., 2016). Defined in this way, market agencements have the capacity to act (Çalişkan and Callon, 2010). In our article, we highlight the fact that they act on two joint markets, that of tomato production and that of beneficial insects. The commodification of insects is a process that creates demand, supply and the market itself, in the same movement, while also creating demand and supply in the tomato market. We examine this interdependency through the notion of market co-creation. This refers to a situation where several

interdependent market agencements grow and interact together in a manner that is favourable to them all.

Our article is therefore in line with research that examines relationships between different markets and in particular the role that procurement markets play in the development of a product or service. For example, E. Fouilleux and A. Loconto's article (Fouilleux and Loconto, 2017) on multi-layered markets analyses the way in which public authorities within the European Union use regulations to construct associated markets: the organic product market, the standards market, the certification services market and the accreditation services market operate interdependently. Our focus is different: the markets we study were not designed to be linked together and their interdependence came about over the course of their development. In analysing this articulation, our article takes the study of market interdependence beyond the specific case of the dovetailing of a goods market with service markets as organised by public action. In this way, we seek to take a step forward in the analysis of market agencements. This concept is often used for descriptive purposes, to report on the configuration of the market being studied. The research thus accumulates a set of singular descriptions, market by market, but without articulating this diversity. The aim here is to provide a more in-depth description of the capacity for action of market agencements. From this perspective, the co-creation of the tomato market and the market(s) for beneficial insects is a specific form of market agencement that might be found in other contexts.

4. Results

Our demonstration is organised as follows. First and foremost, our article looks back at the emergence of the beneficial insect market and shows that it cannot be separated from the dynamics of the tomato market. It then examines interactions between insect suppliers and tomato growers in order to define the products and services that are offered. Finally, the article focuses the market work of two economic actors: the tomato producer organisations who buy the insects and the insect sellers who provide a consultancy service. The "market work" of these two types of mediators (Latour, 2005), POs and technical sales representatives, is vital to the co-creation of the two markets.

4.1. A story of market co-creation: the emergence of the beneficial insects and pollination markets

Due to the high proportion of soilless growing, the tomato production sector is generally considered to be a symbol of industrial farming, even though we might consider that, as in Australia, farms are run by entrepreneurial farming families (Pritchard et al., 2007). Yet this development was only made possible by the early existence of beneficial insects in greenhouses, which constituted an unprecedented combination of nature and artifice (Harvey et al., 2002, p. 102-129) and supposed the concomitant development of a market for insect suppliers – an evolution that is far less frequently examined.

4.1.1. Insects vital to the pollination and health of greenhouse tomatoes

The current tomato production model, soilless and in huge heated glass greenhouses, was a fringe development in France in the 1960s, followed by major increases in the late 70s and throughout the 80s (Brun et al., 1985). Since then the system has been perfected, with taller greenhouses, better impermeability, improved heating techniques (cogeneration), smart plant sensors and significant levels of computerised crop monitoring. More technological

equipment nevertheless goes hand in hand with greater recourse to nature and to insects in particular, the latter being indispensable production auxiliaries with regard to both pollination and crop protection.

One of the most important challenges in soilless greenhouse production is pollination: the tomato flower has no nectar and is therefore not very conducive to pollination, being of little interest to numerous insects which would ordinarily fulfil the pollinating function (bees for example). In the early days of greenhouse growing, growers would use electric vibrators several times a week to artificially produce pollination. In the late 1980s, the release of bumblebee hives became more widespread, with the bees helping with fructification when they collect pollen. Insect presence drastically reduces the workload, thus improving efficiency.

> Up until 1988-1989, until BIOBEST turned up with its first hives, pollination was done manually. By vibration. Growers achieved this either by simply using a stake or with a vibrator that vibrated all the tomato plants to shake out the pollen. So the pollen was dispersed onto the pistil. But you have to do that at just the right time, because if it's too damp, the pollen won't be shaken off, and if it's too warm the pollen is sterilised, so in fact you can quite easily do all that work for nothing. You used the vibrator on 25,000 plants and you got zero fruit because you didn't do it at the right moment. It was very laborious, very time-consuming and not always very efficient.
>
> Farm technician, 2018

To encourage bumblebee uptake, the cost of this type of pollination was based on that of the electric vibrators. In addition to comparable costs, bumblebees provide a better quality

service, even in bad weather. It was these qualities that gradually made them essential to high-yield production.

The necessary presence of bumblebees in greenhouses also had collateral effects on the types of crop protection that might be used. The level of service that they provide can only be maintained if the bumblebees are alive and in good health, something that is not compatible with a wide range of phytosanitary treatments. All of the producers invited to tell us about the circumstances that led them to opt for IPM (Integrated Pest Management) emphasised their precursory role. Without bumblebees, pollination would be impossible, so it was because these bumblebees had to be kept alive that many tomato growers began to look at all the possibilities of biological control. Producer trajectories for the adoption of IPM therefore vary (Lamine, 2011) and we might suppose that many tomato producers are accidental environmentalists (Marr and Howley, 2019).

During the 1990s, when it became clear that bumblebees had to be kept alive if one wanted to reach a decent level of production, biological control was nothing new and was already being used in tomato production. *Encarsia formosa*'s effectiveness against whitefly had been proven in the interwar period (Speyer, 1927) with more than 1.5 million of these parasitoids being sold every year in Great Britain (Hussey and Bravenboer, 1971). This method nevertheless ran out of steam after the Second World War, due to the commercialisation of effective insecticides that were cheap and easy to use. The rapid appearance of resistances among red spider mites led a group of British researchers to show a renewed interest in biological control: they revealed the effectiveness of *phytoseiulius persmilis*, a predator of these mites. Finally, in the 1970s the stabilisation of knowledge concerning the *encarsia* and the *phytoseiulius* and their effectiveness against pests led to the development of large-scale insect farms in both Great Britain and Holland (van Lenteren and Woets, 1988).

While the appearance of resistances encouraged farmers to use biological control to grow tomatoes, in the mid-1990s this method was also bolstered by the availability of another beneficial insect - *macrolophus pygmaeus*. The latter is a predacious bug that has the advantage of being universal, i.e. it attacks several types of tomato pests. As this technician explains, little by little it replaced several other beneficial insects:

> When the *macrolophus* was introduced, it ate leafminers just as much as it ate whiteflies and mites. So the suppliers thought *"We'll stop producing parasitoids that are far more complicated to farm"*. The *macrolophus* is far easier, far more cosmopolitan, polyvalent, transversal, very practical. (…) The *macrolophus* was very easy to use. It was very visible too. It's true that a market gardener also needs the reassurance of seeing what he/she's doing. When you have a load of microscopic things like *encarsias*, you can't necessarily see them, the producer doesn't really know if it's working, if it's not working: *"I don't know, I can't see. Are they ripping me off or tricking me?" [She laughs]*. (…) You can see a *macrolophus*, it's big. Big in insect terms of course! It's green, it moves, it flies, it's easy to see. And it's true that psychologically speaking, for a market gardener it's easier. You see it, it bites you, it moves!
>
> Technician, 2018

To protect the bumblebees and cope with the resistances induced by phytosanitary products, biological control became commonplace in tomato production greenhouses. The distribution of beneficial insects involves processes of commodification, which here take on a specific dimension in as much as they concern living entities. While the economic sociology of food products has clearly highlighted their variability and perishability, for example for fruit and vegetables (Anon, 2013, Freidberg 2009) or fish (Le Velly and Dufeu, 2016), insects are products that must be kept alive throughout the marketing

channels, which is fairly atypical. This is a peculiarity that is dealt with not only by suppliers but also by customers, individual producers and POs (see 4.2). More generally, the success of beneficial insects must be placed in the context of the directions taken by tomato producer organisations, which bolstered this evolution.

4.1.2. Beneficial insects at the root of economic strategies

The use of insects in greenhouses is not only a vital production component, it also makes it possible to develop economic strategies to add value to tomatoes. First of all, the effectiveness of bumblebees can be linked to the segmentation of the product offering that characterises the market: while the round tomato accounted for 95% of the fresh tomato market in the mid-1990s (Hassan et al., 2009), diversification was made possible by the large-scale production of varieties that relied heavily on beneficial insects for their pollination: for example, the development of vine tomatoes can be explained by their presence in greenhouses. The same is true of the development of small fruit sales (round or plum cherry tomatoes, cocktail tomatoes, etc.) which require excellent pollination in order to grow – something that would not have been possible with electric vibrators.

> There was a parallel evolution, the use of pollinators and variety development. The PO began to work on vines. It was in 1993 that vine tomatoes really began to be marketed on a large scale and cherry tomatoes too. It was the same period that bumblebees were developing too. So they really both happened at the same time. We wouldn't have had vine tomatoes if we hadn't had bumblebees.
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> Technical sales representative, west, 2018

The increasing use of insects for integrated pest management allowed an entire sector to valorise its production methods. This is particularly frequent for food products, whether

this be in relation to a terroir (Stanziani, 2004), or in the context of fair trade (Raynolds et al., 2004) or organic agriculture (Buck et al., 1997; Hansen et al., 2006). In our case, tomato growers valorise the replacement of phytosanitary products by beneficial insects; to this end, they commit to a third solution, between conventional and organic agriculture, through the creation of private "pesticide-free" labels. Here they rely on the market work carried out by the POs and the insect suppliers' technical sales representatives, who work together to create new product categories for the tomato market.

The tomato sector is very much organised around the "Association des organisations de producteurs *Tomates et concombres de France" (AOPn)*. This association supported the introduction of integrated pest management during the 1990s. In particular, it had made said protection obligatory for all of its members, via the 1998 national "Tomatoes of France" charter (Bouhsina et al., 2009). Verification of compliance with the charter generally involves analyses to check for pesticide residues and an audit of growing practices (one audit per PO per year) with inspections at 25% of production sites and 100% of packaging sites. The purpose of this audit was to check that phytosanitary treatments were only used when they were strictly necessary, i.e. when biological control could no longer cope with attacks by pests and pathogens. The objective of the charter was to get all grower members to adopt a common approach so as to reduce the number of specific demands made by buyers. Due to pressure from consumer associations, in the 2000s major distributors' central purchasing departments changed their contractual specifications to impose an even more restrictive use of phytosanitary products: residue analysis no longer had to meet maximum residue limits (MRL) but instead a percentage of these MRL (70% for the most part and down to 30% for the most demanding); a maximum number of substances was also set (usually 3 or 5) (*Anon*, 2012). Such specifications were not

achievable without properly controlled integrated pest management, which reinforced the use of beneficial insects.

Since 2017, several producer organisations have voluntarily taken steps to create consumer information labels. Two of these are currently in use: "zero pesticide residue" (Rougeline and Océane brands) and "No synthetic pesticides from plant to plate" (Solarenn, Savéol and Prince de Bretagne brands[2]). In order to ensure that the commercialised product contains no traces of phytosanitary products, growers have had to significantly intensify biological control, which has in turn considerably increased the consumption of beneficial insects.

> This year, like many of its competitors [the PO] is risking everything on "zero pesticide" products. They are doing a huge amount of advertising in that respect (…). Take *macrolophus* for example, the idea was that [the PO] made approximately 15% of the surface area zero pesticide. Except that they hadn't thought about one simple thing, which is that in the large tomato greenhouses there are several varieties of tomato. It varies from greenhouse to greenhouse but there might be 3 or 4 different varieties in a single greenhouse. Which means that if you are going for "zero pesticides" for one variety in the greenhouse, it's the entire greenhouse that is zero pesticide and not just the variety that was planned to be zero pesticide. So it's the whole greenhouse that has to be without pesticides and there are two ways of achieving that: by using a huge number of yellow sticky strips to attract the whiteflies and a whole load of *macrolophus* – absolutely phenomenal quantities compared to a normal season. And that's not something we saw coming. (…) this week I think we have to supply between 250 and 300,000 macrolophus,

[2] According to one of the actors we met during the study, the existence of two competing labels can be explained in part by competition between producer organisations and in part by differing interpretations by fraud inspection services.

whereas last year at the same period we must have been at 50,000. It's true that multiplying by 5 means it's a whole new ballgame for us.

Technical sales representative, 2018

If growers are accepting this evolution it is because it gives added-value to their produce: *"in this segment the aim is to sell approximately 30% in this product range and maybe hope to get 10% to 15% more added-value"* (Quality manager, 2018). During our study, our interviewees confirmed that they were managing to sell tomatoes bearing this label at a higher price.

To summarise, this first section has shown that not only are insects vital to greenhouse production of tomatoes, but that they also form the basis of the sector's economic strategies. We propose to refer to this interdependent development between the tomato market and the insect market as "market co-creation". This section has allowed us to show how the tomato market benefits from the insect market that, in turn, it is helping to promote. We will now look at how the tomato market affects the insect market, not in terms of quantities produced, but in determining the quality of the products supplied; this depends not only on the characteristics of the insects, but also on their packaging and on the conditions in which they circulate.

4.2. Interactions to configure the beneficial insect market: when the tomato growers get involved

For tomato producers, biological control means working with insects, which is a significant change from using phytosanitary products. Insects have a set of characteristics that make them complicated to use and to trade: they are a live product, hard to recognise and with an effect, or service, that is not easy to evaluate. Producers (individually or within

pre-existing groups) have gradually introduced methods for evaluating products, so as to reduce trading uncertainties pertaining to the quality of what they are buying. Although these do not suffice to remove all uncertainty, they are part of the process of attachment between product and customer (Le Velly and Goulet, 2015; Callon et al, 2002). Insect sellers also play a role in these processes of attachment by adjusting their supply accordingly.

4.2.1. The complex assessment of "insect" products

The "inundative" biological control used in tomato greenhouses supposes the massive release of insects on a very regular basis – every week or fortnight for *encarsia*, for example. Growers are therefore constantly receiving and introducing insects. But because this is a live product, its effect is not always the one that was hoped for and sometimes there is no effect at all. Sometimes the insects do not manage to establish themselves, or their release does not resolve the problem, without anyone being able to offer an explanation.

From the tomato growers' standpoint, one of the main difficulties when it comes to assessing insect quality is that it is not always easy for them to recognise the type of insects they are seeing. Furthermore, not all growers are interested in having precise entomological knowledge of the insects that are released, especially when they delegate this task to a technician or their crop manager. Such uncertainty with regard to the nature of the product has various causes: the majority of beneficial insects are small, hard to see and even harder to recognise without entomological knowledge. Under such conditions it would be illusory to hope to be able to identify insects whose genetic mutations have altered their predacious abilities. Such contaminations were described to us as being

laboratory accidents, in a non-commercial context. It should be noted that guidelines for the preservation of insect quality during rearing were published in the early 2000s (van Lenteren et al., 2000). More generally, there are doubts concerning the effectiveness of farmed insects, which may be less than that of insects naturally present in the environment. Moreover, growers have very little information on how these products are reared. The insects that the producers receive have no specificities that would allow them to identify the company that reared them. On the contrary, a certain number of incidents alerted growers to the fact that for certain insects, their suppliers may have called upon a small number of sub-contractors: the suppliers were selling the same product, but with different packaging. Here is what one of the technicians we interviewed had to say on this matter:

> We don't really know the location of the farm that supplies the insects we buy. In some cases I have absolutely no idea where they come from. They bear the [supplier's] mark, but they don't all come from [that supplier]. It's true that that can be very unsettling. Indeed, when we read about problems of quality among aphid parasitoids, it made us wonder. We told ourselves that *"we can try parasitoids from X, from Y, from Z, but who knows, maybe they're all from the same farm"*. It's just that there are three different labels for the same bug. And there's no way the suppliers will tell you where they come from. (…) Just when there are major technical problems. Four years ago the hives [from this supplier] were held up in Belgium, they'd found a bee pathogen in the bumblebee colonies. So they were no longer allowed to cross the French border, so suddenly [the other supplier] came to see us and said *"We don't have any more bumblebees"*. That's how we knew that [the second supplier's] hives came from [the first].
>
> Technician, 2018

Faced with this problem, producers resort to a very simple method of assessment: they check that the delivered insects show signs of life, independently of any precise identification. Are they moving? What is the larva/adult ratio? Are the parasitoids still in egg form or have they prematurely hatched? Some growers isolate a strip of insects in a jar to check that hatching has occurred. These various procedures are approximate and are not systematically used. So producers do not really have any means of checking the merchandise they receive and transactions rely to a large extent on trust – trust in the insect company and its reputation.

In addition to the characteristics of the insects themselves, product quality depends on the packaging, which is more or less suited to greenhouse growing. Three types of packaging are used: for adult insects, bottles in which there is also a support (often vermiculite and bran) along with food for the journey, all of which is distributed into saucers at the foot of the seedlings; sticky strips onto which the eggs are placed, and finally sachets that are attached to the tomato seedlings. Criticism of the bottles generally relates to the support inside which can sometimes squash the insects and cause a high rate of mortality. As this crop manager explains, criticism of the sachets concerns the way they are attached:

> Packaging is sometimes more important for some growers than for others. For us it's important. At the moment we are having problems with the *andersoni* sachets, which are too flexible. We attach them, but as soon as someone hits them, the sachets fall to the ground. Such details are very important and they'll be mentioned in the negotiations at the end of the year.
>
> Crop manager, 2018

These "details that are very important" show us that the task of qualification does not end with the sale of the product to the end user, it continues as the product is used. The use of

beneficial insects implies an evolution in growing practices, and reciprocally said practices help to define the product. Product assessment therefore remains a delicate matter: while it in fact has little to do with the insect itself and with its biological nature in particular, customers refer to various characteristics specific to the product, which allow it to be adjusted to the end user (Callon et al., 2002). A quality product is delivered on time, alive and in packaging that is suitable for its use in intensive greenhouse growing. Each of its characteristics is subject to negotiations between supplier and customer (whether the latter be an individual producer, represented by a collective organisation such as a PO, or assisted by a local advisory structure). Through such negotiations, these actors produce market work (Cochoy and Dubuisson-Quellier, 2013) that has gradually led to stable traded products.

4.2.2. Product improvement through the supplier-customer relationship

When faced with quality issues, growers are less prone to criticise the product itself and focus more on the conditions of transport: delays due to strikes, to poor logistical circuits, to cold weather or heatwaves, to public holidays, etc. They all told stories about sometimes not receiving their deliveries or taking delivery of another grower's order or about transport conditions that had led to high mortality rates. Generally speaking, disputes between customers and suppliers are resolved by a replacement delivery being made or with discounts being offered on future orders. Given that biological control is based on a capacity to observe and detect the presence of pests as early as possible, in order to release massive quantities of beneficial insects, such a response is only partially satisfactory for a customer whose biological control strategy has been compromised by said delays. Growers have therefore come up with strategies that are both *individual* and *collective*, using pre-existing organisations in the tomato market to evolve logistical flows and ensure their

supplies. So, market co-creation was not limited to the early stages of the beneficial insect market; it continues to impact trade.

First of all, certain growers have come to an agreement with their technical sales representative so as to guarantee deliveries that are better suited to their specific situation (large one-off orders for example), with better controlled deadlines or in order to derogate from the rules common to their geographical sector. For example, a technician on a farm specialising in integrated pest management explained that she had adapted the frequency of her orders in order to allow her supplier to meet her requirements. She gives 5 weeks advance warning when she needs *andersoni* (an insect that is complicated to rear). This arrangement ensures that she gets the right insect at the right time. Similarly, another grower negotiated that he would be one of the first customers to receive deliveries each week, to ensure that the insects introduced into his greenhouses had not travelled too far. Once again, these more or less tacit agreements, reached after talking to the insect suppliers' technical sales representatives, are decisive.

In addition to these individual answers, which concern growers who have huge greenhouse surface areas and who are therefore major customers, some producers gave their opinions on the consultancy structures in their region. This is the case in the Nantes region where growers entrusted a regional support body – the Comité Départemental de Développement Maraîcher or CDDM (regional committee for the development of market gardening) - with the task of assessing the quality of the insects delivered within their producer organisation. The assessment revealed high levels of mortality, causing certain suppliers to modify their logistical circuits by setting up refrigerated warehouses in the region.

> I know that at one time some people were complaining about a delivery of *encarsias* and other insects, because when they arrived, half of the eggs had hatched on the sticky strips. So at that time the CDDM did a few small surveys.

> They found out that the quality of insects delivered by some suppliers was awful, with 50% of the *macros* already dead inside the *macro* bottles. Studies had been done. They had already shown that the quality of the service and of the supplies was important. (…) That's more than 10 years ago now. I think things have improved since then. Some of them have built warehouses so they can store. And the number of shuttle aircraft has also increased, which means that there's less time between ordering and delivery. Delivery services have been set up. At one point, when they had been put into competition with respect to quality, they tried to improve their offering and their service to achieve a certain quality.
>
> Producer, 2018

These examples show how the insect market has evolved in terms of the interactions and agreements between growers and technical sales representatives. The most classic forms of relationship (discounts and replacement deliveries) concerned small growers, in as much as they order small volumes of insects and are not stakeholders in an organisation of producers whose clientele is sought after. Producers whose clientele is sought after, either because they themselves order large quantities of insects, or because they belong to an organisation which does so, have obtained arrangements concerning logistical flow that provide them with stronger guarantees in terms of the availability of rare insects or shorter transportation times.

In this section we have highlighted the fact that working with insects creates uncertainties, especially with regard to the effectiveness of crop protection: producers try to reduce uncertainty, either by using individual quality control techniques, or by calling upon pre-existing and well-organised peer groups in the tomato sector. This allows them to better define the products and the conditions of sale that they require.

4.3. The co-creation of markets: focus on the market work of POs and consultants

Previously in this article, we showed how opting for biological control is not simply a matter of individual decision making by the grower (Moore, 2008; Thomas et al., 1990) and how producer organisations play a central role in this evolution, allowing them to grow tomatoes that meet customer specifications. In this final section we will focus on these two types of intermediary, the POs and the technical sales representatives, and we will show how their work is part of the market agencements that link the insect and tomato markets.

4.3.1. The dual market intermediation by POs

Researchers in the fields of sociology and economics have long been interested in the strategies of producer organisations (Dubuisson-Quellier et al., 2006; Codron et al., 2017; Groot Kormelinck et al., 2019). Various typologies have been put forward, in particular to analyse their role as market intermediaries and the types of articulation that exist between growers and their clientele. The principal task of all tomato POs is to put production onto the market. Over the last twenty years or so, in order to guarantee the quality of their products, they have developed technical assistance for producers that encourages integrated pest management. We are going to examine their strategies regarding insect supply and the choices they make with regard to technical assistance for producers in POs.

The field study shows that insect suppliers' customers are not always individual customers, but rather their producer organisations. In concrete terms this means that some producer organisations negotiate and sign contracts on their members' behalf. If we set aside the example of the PO that created a beneficial insect biofabric for its growers, we identified

three strategies for supplier selection: while it is rare, certain POs allow their members to be entirely autonomous in making their choices; others make a contract with a single supplier for all members; and others choose to share their growers among several suppliers, in which case the idea is to guarantee supplies by not having to depend on a single beneficial insect source – which demonstrates the vital nature of the latter.

> At the end of the day we try to somewhat share the market between the two service providers. There's approximately 50% of the surface area at [one of them] and 50% at [the other]. (…)
>
> *And why do you share the market? What is the idea behind that?*
>
> Because we're always worried about being in short supply, particularly with regard to hives. There are periods in the year when hive supply can get quite tense. If you have several suppliers you split the risk. On paper that seems to be a good strategy.
>
> Quality manager, 2018

In addition to negotiating contracts with beneficial insect suppliers, within the framework of operational programmes relating to the common organisation of markets[3], POs also cover all or part of the cost of integrated pest management, and hence the purchase of insects. Methods of calculating aid for producers vary from one PO to another: some offer a fixed annual price that includes a consultancy service provided by the PO's technicians; others charge per hectare or a number of insects per square metre. But whatever the method, this reduces the cost of integrated pest management for the growers.

[3] The fruit and vegetable sector benefits from financial support within the framework of the Common organisation of the markets, governed by Regulation (EU) 1308/2013 of the European Parliament and Council Single CMO and the Commission implementing regulation (EU) 543/2011 CMO fruit and vegetables. The operational programmes are business projects established over 3-5 years which may be granted subsidies for the market entry or improvement of product quality. Only POs (and not individual producers) may benefit. Cf. terms and conditions on the FranceAgriMer site: http://www.franceagrimer.fr/filiere-fruit-et-legumes/Aides/OCM/Programmes-Operationnels-PO

Finally, some producer organisations provide their members with specialist technical assistance in biological control. The use of insects involves a change in agronomic practices: for example, during certain periods of the year it is necessary to heat the greenhouses to ensure that the beneficial insects establish themselves properly; on the other hand, leaf removal, which boosts productivity, is not recommended from a biological control standpoint because the insects live on the leaves, especially those found on the lower stems of the seedlings. Finally, throughout the growing season it is vital to monitor increases in pest populations in order to optimise the release of beneficial insects. Certain PO employees are able to perform this task, as this technician explains:

> I observe what happens at growers' farms. (…) The first three months of growing are the months when the plant develops, establishes itself, it's not yet an adult plant; I visit the farm every week and I do a count on 20 plants (to see what kind of pests are there). And then I visit every fortnight to do counts. But if there is a real problem then I might visit every week, but in that case I don't do any counts because that takes time. I know enough to see whether the populations are increasing or falling. Whether there are problems or whether it's getting better. Then when all the counting is done I talk to the grower, I say "okay, there's this or that problem at this or that spot" and we think about what action to take.
>
> Technician, 2009

Negotiating procurement contracts with insect suppliers, paying costs in part or in full, providing technical assistance with the use of beneficial insects… PO support is therefore vital for the implementation of integrated pest management. Given the production and marketing objectives on the tomato market, this support makes sense. Tomatoes are affected by many plant diseases, with consequences such as black marks or small golden dots that make it difficult for the POs' commercial services to sell them. In addition,

supporting biological control on growers' farms is a guarantee that a tomato sold with a pesticide-free label has been grown only with the help of beneficial insects. Lots sold to supermarket buying groups are regularly analysed and the presence of residues on a single vine would tarnish the reputation of the entire organisation and thus penalise all its producers. For POs, support for biological control is therefore an essential component of their marketing strategy (Anon, 2012).

The market work carried out to sell tomatoes is based on the purchase of beneficial insects: producer organisations need large quantities of high-quality insects, which strengthens the market for beneficial insects. Their demand for insects is massive and sustainable over time, thus allowing insect sellers to develop. In return, the insect producers' technical sales representatives provide producers with a consultancy service that supports the POs' strategy.

4.3.2. Selling insects while at the same time improving producers' skills in terms of biological control strategy: the market work of the technical sales representatives

We have shown how the use of integrated pest management to improve crop health requires an evolution in growing practices. As a result, insect suppliers generally offer a technical assistance service (Le Velly and Goulet, 2015). Over the years this service has taken various forms: when farmers began to use biological control, they learned from the consultants advising insect suppliers, who worked both with individual farms and with farmers' groups.

> In fact, [the insect company] needed the CETAs[4]. It needed them in order to be able to move forward, because when they opened an office in the region, success was by no means a foregone conclusion. At the beginning they were on their own (…). They developed well, they recruited employees, technicians who were technical sales representatives but who taught us how to count. Nowadays, every week [our own technician] counts in all the rows: what have we got? What do we need? Is there anything harmful?
>
> Producer, 2019

The sale of insects has always included a user support service designed to pass on entomological and agronomic knowledge (in a completely different field, cf. Mallard, 2012): recognising insects, being able to assess whether there are sufficient numbers to contain pests and diseases. The market work carried out by insect sellers thus contributes towards the acquisition of skills and to the definition of farming practices… and hence to the transformation of the agricultural system.

It should also be noted that tomato growers use the term "technician" to describe representatives from insect companies who visit their farms, and several of our interviewees stressed their competency and even their vocation for agricultural entomology.

> Above all they are technicians. They are passionate about bumblebees. Sometimes people say *"He tried to flog me some…"*. I don't believe that, it's not true. They are technicians first and foremost and it has to succeed. And when it succeeds, it

[4] A Centre d'Etudes Techniques Agricoles (centre for technical agricultural studies) is a group made up of farmers who pool their experiences in order to improve farming practices. These groups were a very important factor of development during the second half of the 20th century. In the tomato sector, the CETAs disappeared with the arrival of POs.

> doesn't matter how much you've spent on bumblebees or insects, you're going to make an even bigger profit. (…) (My supplier) is an enthusiast, he's a missionary.
>
> Producer, 2018

Not all of these consultants offer the same type of assistance. Some of them only visit the growers twice a year, just before planting to set out the framework of the relationship during the growing season, present the available products (the various insects and their marketing materials, along with staple products such as food or pheromone trapping devices…) and then at the end of the season to discuss any issues. Communication thus takes place for the most part by telephone and via the supplier's website. This is the case for producers who have acquired a high level of skill or who have recruited specialist personnel. But even then, producers and technical sales representatives keep in touch in order to regularly exchange information. Other technical sales representatives from insect companies deal with a large part of crop protection in the farms: they detect the pests, monitor their development and even release the beneficial insects, visiting the farms on a very regular basis, every week. In such cases the growers are essentially buying a service. Moreover, while they are all aware that the purchase of a service represents an additional cost for the farm, over and above just buying the insects, producers who choose this option (particularly when they have selected a distributor) do not consider that they are paying for the same thing: they are looking for efficacy, for specificities that suit their greenhouses and for a complete catalogue of products with multiple suppliers.

> I think I pay 20% more for my hives, but I don't work with the same bumblebees. (…) In fact, [the consultant] pointed something out: depending on the period and the site, he doesn't install the same hives. He doesn't use the same species of bumblebee. He knows that here, as from April/May we have problems with the ash trees on the other side of the Loire, and at one time, when we had greenhouses that

> were lower down, they were warmer and the bumblebees had problems pollinating, what with the ash trees on the other side, where they escaped to, and the warmer temperature. So every April/May we systematically switch to African bumblebees which prefer the warmer temperature and which don't cause us any pollination issues. On top of that, they provide a one-week make-to-order service, something we don't get with [the specialist company].
>
> Producer, 2018

With the exception of one PO that looks after major growers who are to a very large extent autonomous, these organisations play a fundamental role in introducing beneficial insects into farms. This role is based first and foremost on the supply contract, which includes the choice of supplier and partial responsibility for the costs. It can be extended to cover technical assistance with insect deployment and with the adjustments to production methods that the presence of insects makes necessary. The association or dissociation between consultancy and supply redefines both the product traded on the insect market and the relationships developed between the actors.

Discussion

The sociology of market agencements would appear to be a useful theoretical framework for analysing the creation of the most diverse markets, particularly in the agri-food sector. For example, it can be used to analyse the emergence of new product segments, that are high-quality (Le Velly and Dufeu, 2016) or which take ethical issues into account (Buller and Roe, 2014; Miele and Lever, 2013). Moreover, these agencements are not established once and for all: they are constantly evolving in line with the market work done by economic actors and have their own capacity to act. A great deal of research describes

these agencements in detail and examines how they create a given market, highlighting their wide diversity. In our article, we broaden the perspective a little: we show that the agencements of one market can also impact the agencements of a second market that is linked to it - a supply market for example. We account for this phenomenon through the notion of "market co-creation".

The joint study of the beneficial insect market and the fresh tomato market allows us to highlight the specificity of their relationships, which cannot be reduced to those found between markets that have already been analysed (Fouilleux and Loconto, 2017). We have attempted to explain these relationships through the notion of co-creation, which underlines the interdependencies that encourage the respective development of these markets. Firstly, the supply of beneficial insects has proven to be essential to the production of tomatoes in the social system of glass greenhouses and to the resolution of certain technical obstacles, particularly those relating to pest resistances to crop protection techniques that have been used so far. By improving methods of pollination, it has also made it possible to grow different varieties of tomato on a large scale, thus favouring market diversification and segmentation and providing further opportunities for valorising production. Secondly, tomato growers participate in product qualification and in the structuring of the insect market. By virtue of their practices and through their interactions with sellers, they test the characteristics of the products and help to improve them. This is true with regard to the insects themselves, their packaging and transport and the way in which they are released into the greenhouses. In taking part in this way in the qualification process tomato producers play an active role in the dynamics of adjustment between insect buyers and sellers, thus helping to structure the market. Thirdly, we focused on the market work of two economic actors: tomato producer organisations and insect sales representatives. We show that while their main activity relates to their respective markets,

they also carry out mediation work in the linked market. More often than not in charge of organising supplies for their members, POs also provide different forms of technical assistance. Depending on their strategy in this regard, advice on biological control is variously divided between the supplier, the specialist consultant and the PO technician. At the same time, we see that all insect sellers are also biological control consultants. For several decades, they have provided both the insects and the entomological information on their use, while at the same time promoting skills development among tomato growers, which supports the latter in their choice of integrated pest management.

Market agencements thus have performative effects that concern not only the market being studied, but also those linked to it, and we report on this through the notion of "market co-creation". The notion of co-creation is nothing new in science and technology studies (e.g. Akrich, 1992) or in marketing (e.g. Harrison and Kjellberg, 2016; Leclercq et al, 2016). In marketing research, co-creation refers to the process through which consumers contribute towards the development of a new product or service (Prahalad and Ramaswamy, 2004; Lusch, Vargo et Wessels, 2008). In the sociology of science, the notion has been used, for example, to describe devices for public engagement with the aim of democratizing science-society relations (Krzywoszynska et al., 2018). In both cases, co-creation refers to a process that relies on interactions between two types of actor (companies and consumers or scientists and the public) who take part in a common project with a specific objective.

In our case, the focus of the analysis is different: while product improvement through the supplier-customer relationship is indeed a co-production, with the notion of co-creation we consider two types of market agencement together and show that they are of mutual benefit to one another. The notion thus goes beyond an interaction between two actors to participate in the development of an innovation or a new service or product:

First of all, market co-creation concerns a larger number of players, be they human (consultants, producer organizations, suppliers' R&D teams) or non-human (insects, tomatoes). Market agencements also involve devices, such as packaging or logistic circuits, without which the articulation of different markets cannot be achieved.

Secondly, the notion of market co-creation can be detached from the issue of intentionality. While in the co-creation of products studied by marketing research, consumers must commit resources (time, skills, etc.) to co-create with the company concerned, this is not the case with market co-creation. In the tomato market, while there may well be interactions that clearly aim to change the insect market offering (e.g. when growers ask for the development of a specific type of research or for packaging modifications), there are also dynamics in this market that are not specifically geared towards the supply market but which nevertheless affect it (making integrated pest management mandatory in a charter, or the hiring of specialized technicians in farms or POs). Similarly, when the insect market's distribution system changes, it affects how producers view technical advice on their farms. Most of the time, everyone therefore continues to act on "their" market, in accordance with periodically stabilized arrangements, in the way that best suits "them".

Finally, and in line with the above, we might describe market co-creation as a complex dynamic because it depends on a very wide variety of human and non-human entities and is mediated by devices. Two co-created markets co-evolve in harmony, thus contributing towards the stabilization and strengthening of their market agencements. We believe that taking market co-creation into account is very important in the analysis of agri-food chains, as it allows us to highlight the complex relationships between interdependent markets, for example the agri-supply and production markets, and even through to consumption.

To conclude, our article contributes to reflection on markets transitioning towards a more environmentally friendly agriculture. Agricultural transition can be analysed as an individual choice of farmers, based on their motivation and attitudes (Wyckhuys et al., 2018). It can be envisaged in farmers' groups, in line with the rural development model that has been implemented since the Second World War. We propose that it should also be observed in the light of the market work of the economic players in supply markets. If we consider that farmers have to market products that they have grown using a different method, this supposes that the market and socio-technical devices in which they operate co-evolve with them. The beneficial insect and greenhouse tomato markets are one example of symbiotic co-creation. Perhaps other agri-supply products could be studied according to the same logic: biocontrol products, greenhouse equipment, above-ground buildings, storage silos, etc. This type of research would also make it possible to produce operational knowledge to regulate these markets by taking into account their interdependent and reciprocal relationship.

Our article is thus an invitation to broaden reflection to include sociotechnical devices of transition and their commodification. Further studies in this perspective would make it possible to better highlight the conditions under which market agencements can be articulated to produce beneficial effects.

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