Do farmers participating in short food supply chains use less pesticides? Evidence from France

Pierre Chiaverina, Sophie Drogué, Florence Jacquet

Do Farmers Participating in Short Food Supply Chains Use Less Pesticides? Evidence from France

Pierre Chiaverina[1][2], Sophie Drogué[1] and Florence Jacquet[1]

Abstract: Proponents of short food supply chains (SFSC) have lauded their environmental benefits. Nevertheless, most studies on SFSCs have focused on their climate impact, while the synthetic pesticide use by farmers participating in SFSCs has received little research attention. In this study, we investigate the effect of farmers' involvement in different SFSC channels on synthetic pesticide use and crop yields. This study relies on data obtained from the 2020 French agricultural census and a 2018 French national survey on the phytosanitary practices of representative market gardeners. This paper uses a multinomial endogenous treatment effect model in order to account for endogeneity. We demonstrate that the effect of SFSC participation on farmers' synthetic pesticide use varies depending on the type of SFSC channel employed. Farmers who sell part of their vegetable crops through direct-to-consumer (DTC) channels use significantly fewer synthetic pesticides than those who only sell their crops through long food supply chains (LFSC). However, there is no evidence that farmers involved in direct-to-retailer (DTR) channels use significantly fewer synthetic pesticides. In addition, we have not found any evidence that SFSC participation decreases crop yields.

Keywords: Pesticides, short food supply chains, local food systems, multinomial endogenous switching/treatment regression

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1 Introduction

In the European Union, short food supply chains (SFSC) refer to supply chains with "*a reduced number of intermediaries*", generally involving no more than one intermediary from the producer to the consumer (Regulation (EU) No 1305/2013). SFSCs have garnered increasing interest from academia and policymakers in tandem with the growing concern of consumers about food provenance and quality and the increasing pressure on the value captured by farmers in conventional supply chains (Marsden et al., 2000; Renting et al., 2003). A growing number of farms in Europe have chosen to market through these alternative food networks (European Parliament, 2016), particularly in France, where 23% of farms participated in SFSCs in 2020 (AGRESTE, 2020)[3]. SFSC development has been supported by the European Union (EU) through the European Agricultural Fund for Rural Development, which devotes up to 10% of its expenditures to the promotion of food chain organization (Dwyer et al., 2016).

Proponents of SFSCs have lauded their sustainable benefits, but the "local trap" critique argues that they are not inherently more desirable than conventional supply chains (Born and Purcell, 2016). In particular, research has called into question their positive impact on farm viability because of their high costs and labor requirements (Chiaverina et al., 2023), and critics have pointed to their social embeddedness as being the preserve of white, educated and wealthy customers (Brown et al., 2009; Hinrichs, 2000; Hinrichs and Allen, 2008). Regarding

[3] SFSC comparisons between European member states are limited, because national data that are collected on SFSCs in comparable ways are scarce (Enthoven and Van den Broeck, 2021). Direct-to-consumer (DTC) channel comparisons are possible but not direct-to-retailer (DTR) channel comparisons because most countries have no data whatsoever on them (Enthoven and Van den Broeck, 2021). The average number of farms marketing through DTC channels for Austria, Belgium, France, the Netherlands and Switzerland amounts to 15.8% of total farms in 2016 (Enthoven and Van den Broeck, 2021).

environmental sustainability, most studies have focused on greenhouse gas emissions issued from SFSCs and report mixed evidence (Coley et al., 2011; Edwards-Jones, 2010; Edwards-Jones et al., 2008).

Such inconclusiveness on the socio-economic and environmental impacts of SFSCs calls for further objective research relying on strong theoretical grounding and quantitative rigor (Malak-Rawlikowska et al., 2019; Stickel and Deller, 2014). In particular, certain aspects of the environmental impact of SFSCs, such as the use of synthetic pesticides by participating farmers, have received little research attention. Only a few studies conducted in the US and Asia examine the impact of SFSC participation on the use of synthetic pesticides and report lower synthetic pesticide use by farmers involved in SFSCs (Lee et al., 2020; Schoolman, 2019; Zhang et al., 2019; Zhang and Yu, 2021).

Scientific studies have consistently revealed that pesticides are responsible for numerous harmful environmental and human health consequences (Carvalho, 2017; Geiger et al., 2010). Nevertheless, pesticide use has continued to increase globally (Zhang, 2018), and the numerous pesticide policies introduced by European member states have not been successful in reaching their pesticide usage reduction goals (Bjørnåvold et al., 2022; Hossard et al., 2017; Lamichhane et al., 2016; Möhring et al., 2020). Pesticide dependency is not only a technological issue for farmers, but also a socio-economic one involving multi-actors and multi-factors that policy frameworks should further consider in order to improve their effectiveness (Hu, 2020; Nagesh et al., 2023). Public support of SFSCs could be a lever to overcome some of the socio-economic obstacles to the adoption of pesticide alternatives. We identify in the literature three mechanisms of SFSCs that could have an effect on reducing synthetic pesticide use.

First, reducing synthetic pesticide use is not always an easy choice for farmers (Lee et al., 2019; Runhaar et al., 2017). The adoption of more sustainable farming practices is hampered by socio-economic, institutional and political constraints (e.g., product quality demands; economic constraints from marketing firms and regulations; lack of technical knowledge; unavailability of agroecological inputs occurring along the whole food value chain) (Boulestreau et al., 2021; Cowan and Gunby, 1996; Guichard et al., 2017; Jacquet et al., 2022; Magrini et al., 2016; Meynard et al., 2018; Togbé et al., 2012; Vanloqueren and Baret, 2008; Wilson and Tisdell, 2001). In particular, farming practices are strongly framed by the constraints of long food supply chains (LFSC), namely constraining farmers to produce large volumes of a few crops while complying with high marketing standards under price and competition pressure. Such specifications may encourage farmers to adopt, and lock them into, unsustainable farming practices (Burch et al., 2013; Lefèvre et al., 2020; Milford et al., 2021; Navarrete, 2009; Zwart and

Wertheim-Heck, 2021). For example, farmers are constrained by retailer requirements and consumer preferences to produce fruits and vegetables with a high cosmetic standard (e.g., minimal pest damage and optimal size and color development), which often requires the use of synthetic pesticides (Pimentel et al., 1993; Yue et al., 2009; Zakowski and Mace, 2022). In contrast, SFSC marketing requirements are less standardized, offering more opportunities and autonomy to implement ecologically sound practices (Bressoud, 2010; Lefèvre et al., 2020; Marechal and Spanu, 2010; Milford et al., 2021; Navarrete, 2009). SFSCs are more likely to adopt pest- and disease-resistant crop varieties that require lower pesticide dependence, as farmers are not constrained by retailer preferences for more established varieties and seeds (Finger et al., 2022; Zhang et al., 2019).

Second, the development of more environmentally-friendly farming practices depends on the capacity of farmers to be economically competitive (Crowder and Reganold, 2015; Reganold and Wachter, 2016; Rosa-Schleich et al., 2019; Sutherland et al., 2012). Farmers involved in SFSCs can make their alternative farming practices financially viable by capturing a value-added premium generated by the reconnection between producer and consumer based on shared goals and values (Mount, 2012; Mount and Smither, 2014; Verhaegen and Van Huylenbroeck, 2001). The tangible and intangible qualities of their products (e.g., authenticity, safety and trust), which allow these farmers to command a price premium, are more easily recognized when the connection between farmers and consumers is closer (Mount, 2012; Verhaegen and Van Huylenbroeck, 2001). This price premium is crucial as it enables farmers to keep up with the disadvantages of potential yield losses associated with the adoption of reduced synthetic pesticide farming practices. The closer relationship between farmers and consumers can even be considered as a substitute for organic certification (Dabbert et al., 2014; Flaten et al., 2010; González-Azcárate et al., 2022; Higgins et al., 2008; Veldstra et al., 2014), as it builds up trust and reduces information asymmetry between farmers and consumers, thus convincing consumers that the products are as good as organic-certified alternatives. As such, farmers engaged in SFSCs can benefit from a higher premium than that fetched by certified organic products, without the financial, administrative and time burdens associated with certification (Onozaka and McFadden, 2011; Veldstra et al., 2014).

Finally, farmers' pest management decisions are strongly dependent on decisions made on neighboring farms, which highlights the importance of peer interactions among farmers (Bakker et al., 2021; Läpple and Kelley, 2015; Stallman and James, 2015). A positive experience with the adoption of alternative pest control methods (e.g., reduced tillage) can be used as a model for farmers who belong to the same network and enhance their intentions to adopt the same methods (Bakker et al., 2021; Stallman and James, 2015). Participation in certain types of SFSCs, such as farmers' markets and box schemes, can develop social interactions between farmers based on technical dialogue and support. Such learning connections among farmers developed through the market can provide them with shared values and experiences that can promote the consideration and practice of more sustainable farming (Chiffoleau, 2009; Chiffoleau et al., 2016; Jarosz, 2000; Lamine et al., 2009; Marechal and Spanu, 2010; Zoll et al., 2021).

The impact of SFSCs on different social, economic and environmental aspects varies across SFSC types (Enthoven and Van den Broeck, 2021; Forssell and Lankoski, 2015; Malak-Rawlikowska et al., 2019; Schmutz et al., 2018); however, most studies evaluating SFSC sustainability do not take into account their variety (Aubry and Kebir, 2013; Lamine et al., 2019). Producers using direct-to-consumer (DTC) chains, such as farmers' markets or on-farm sales, sell directly to consumers without any third-party actor. This close contact with customers allows farmers to keep a greater share of their sales revenues but adds labor and marketing costs and limits scalability (Renkema and Hilletofth, 2022). By introducing just one intermediary that connects producers and consumers, such as a distributor, canteen or supermarket, direct-to-retailer (DTR) chains might be a means of resolving these challenges (Dimitri and Gardner, 2019; Rosol and Barbosa, 2021). Over the past decade in France, the share of farms using DTR chains has risen from 5.3% to 11.2% (AGRESTE, 2020, 2010). DTR channels have also experienced a boom in the US (Low et al., 2015), because they are more conveniently located and offer more complementary food products than DTC channels do (Printezis and Grebitus, 2018; Richards et al., 2017).

However, DTR channels have the potential to reproduce the conventionalization seen in the organic product market by involving mainly large-scale producers with primarily economic motivations. Increased scale and competition in DTR channels can challenge the capacity of farmers to capture a premium and can force them to adopt more intensive farming practices (Ilbery and Maye, 2006; Mount, 2012; Mount and Smither, 2014; Rosol and Barbosa, 2021). Indeed, farmers participating in DTR chains still have to comply with stringent marketing requirements that reward these intensive farming practices (Zwart and Wertheim-Heck, 2021). Mount and Smither (2014) show qualitatively that farmers participating in DTR chains adopt farming practices that are close to those used in LFSCs. Considering all SFSC types to be the same – particularly DTC and DTR channels – might therefore blur the effect of SFSCs on synthetic pesticide use because it combines what could be opposing results of these different SFSC types.

The objective of this paper is to investigate the effect on synthetic pesticide use of different strategies of SFSC involvement in vegetable production, depending on the presence or absence of an intermediary. In particular, we consider the impact on synthetic pesticides occurring from participating in (i) DTC channels, (ii) DTR channels and (iii) a combination of both DTC and DTR channels, compared to participation only in LFSCs. In addition, we examine the effect of these different SFSC strategies on crop yields in order to evaluate the efficiency of their associated farming practices. Low-pesticide production practices can lead to lower yields due to competition from weeds or crop damage caused by pests and diseases (Foley et al., 2011; Tuomisto et al., 2012). Two studies conducted in China show that market gardeners engaged in SFSCs have a lower level of synthetic pesticide dependency and higher yields thanks to the use of improved seed and capital-intensive technologies (Zhang et al., 2019; Zhang and Yu, 2021).

To answer this research question, this study relies on data obtained from the 2020 French agricultural census and a national survey on the phytosanitary practices of market gardeners conducted in 2018. One reason for focusing on market gardeners is that vegetables are the most frequently represented products in SFSCs (Uematsu and Mishra, 2016). The main concern when evaluating the impact of farmer's participation in SFSCs on their synthetic pesticide use and crop yields is that it may be the result of some omitted variables. Unobservable or unidentified variables characteristics might affect the decisions both to adopt SFSCs and to use synthetic pesticides (or not), leading to spurious estimates of the impact of SFSC participation on synthetic pesticide use and crop yields. To address this issue, this paper employs a multinomial endogenous treatment effect model proposed by Deb and Trivedi (2006) that accounts for selection bias and endogeneity originating from observed and unobserved heterogeneity.

The paper is structured as follows. The two following sections define the data and methodological approach used to evaluate the effect of SFSC participation on the application of synthetic pesticides and yields by farmers. The results of the analysis are presented in Section 4 and discussed in Section 5.

2 Data

This study relies first on data obtained from a national survey on the phytosanitary practices of representative market gardeners, conducted in 2018 by the French Ministry of Agriculture Department of Statistics. The survey initially involved 7,323 parcels of carrots, cabbage, strawberries, melons, leeks, tomatoes and lettuces[4]. In this

[4] Strawberries and melons are classified as vegetables in this survey

survey, information is at the parcel or farm level, depending on the nature of the variable examined. In addition, we employ data from the 2020 French agricultural census, which provides complementary information about the socio-economic and production characteristics of vegetable farms. We match the data from the two surveys presented above, thanks to the business identification number assigned to each farm. We end up with a sample of 4,740 market gardeners. Figure A1 in the Appendix provides the municipal location of the farms investigated.

2.1 Explanatory variables

The 2020 French agricultural census gathered information from market gardeners on the SFSC types they used to sell their products. Based on this information, a set of four marketing channel strategies were identified according to the presence or absence of an intermediary (Figure 1). Market gardeners using only LFSCs to sell their vegetables re considered as the reference group and represented 54.3% of market gardeners. The second group, —using DTC channels —included 24.3% of the market gardeners who sold directly to consumers without any third-party actor. This group covers market gardeners involved in the following SFSC types: (1) on-farm selling, (2) door-to-door selling, (3) farmers' markets, (4) collective selling points, (5) community supported agriculture, and (6) online selling. The third group—using DTR channels—accounted for 4.9% of the market gardeners; these market gardeners sell through one intermediary organization that connects producers and consumers. It includes the following SFSC types: (1) direct sales to retailers, (2) direct sales to large stores (3) direct sales to restaurants and (4) direct sales to institutions. The fourth group included 16.4% of the market gardeners who use both DTC and DTR channel types. Note that market gardeners engaged in the various SFSC strategies defined above may also sell a minor amount of their production through LFSCs[5]. The literature has shown that many farmers combine SFSCs with LFSCs (Filippini et al., 2016a, 2016b; Gilg and Battershill, 1998; Thomé et al., 2021).

[5] For example, farmers might sell their vegetables through DTC channels and LFSCs, DTR channels and LFSCs or a combination of DTC sales, DTR sales and LFSCs.

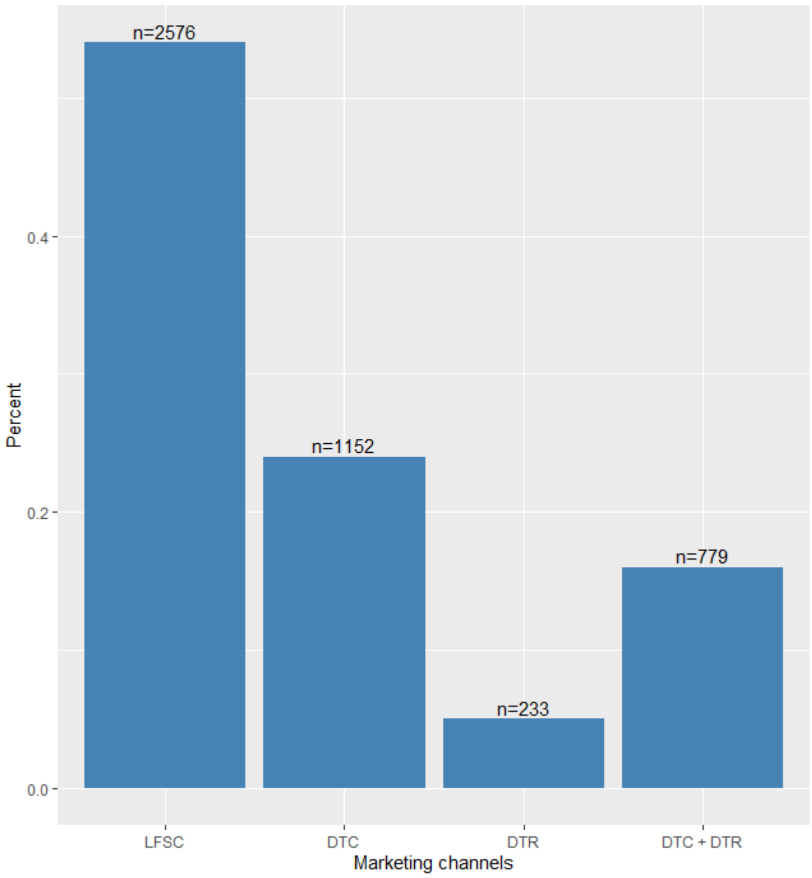

Figure 1. An overview of the different SFSC channel strategies involved in this study.

A key part of defining the appropriate counterfactual condition is clarifying precisely what is held constant while the variable of the marketing channel strategy changes (King et al., 1994). Thus, we controlled for a variety of agronomic, social and economic variables affecting both the decision to participate in SFSCs and the decision to use synthetic pesticides (see Table A1 in the Appendix). These control variables are from both the 2020 French agricultural census and the 2018 French survey on the phytosanitary practices of market gardeners. They include controls for characteristics of the farm's production and farming practices (land use, diversification activities, diversification species, quality labels, organic farming) and of the farm manager (age, gender and education). We also controlled for crops grown and the presence of pest and disease problems on the surveyed parcels. In addition, we included regional effects for 10 administrative regions, accounting for regional differences in farm structure, agronomic conditions, marketing constraints, etc.

2.2 Dependent variables

The Treatment Frequency Index (TFI) is our dependent variable, measuring the use of synthetic pesticides on the surveyed parcels. This index represents the ratio between the applied and recommended doses, considering the area of the treated parcels (Pingault et al., 2009). For example, if the reference dose of an herbicide is spread over the entire area of a plot, then the TFI of the plot equals one. The annual TFI of the entire parcel is the sum of the TFI calculated for each treatment performed on the parcel during a crop season:

$$TFI = \sum \frac{applied\ dose}{reference\ dose} * \frac{treated\ area}{total\ area}$$

Figure 2 reports the median value of the TFI (log-transformed) by crop and marketing channel[6]. Figure 3 reports the median value of the yields (log-transformed) in tons per hectare, by crop and marketing channel. Both TFI and yields are analyzed using the nonparametric Kruskal-Wallis test in order to detect significant differences among marketing channels. For each vegetable, we find that farmers engaged in the three different SFSC strategies have a significantly lower median TFI at the 1% level than do farmers using only LFSCs. The only exception is for market gardeners producing cabbage for DTR channels, who have a significantly higher median TFI than those using only LFSCs. In addition, market gardeners involved in DTC chains or combining DTC and DTR channels exhibit the lowest synthetic pesticide use. In contrast, the link between SFSCs and vegetable production yields is not evident and depends on the crop. The objective of this study is to assess the extent to which differences in synthetic pesticide use and crop yields is attributable to SFSC participation.

[6] We use the log-transformation of the TFI and yields to deal with skewness.

Figure 2. Synthetic pesticide use difference (TFI log-transformed) between marketing channels

Distribution of the TFI for the seven crops and four marketing channels. The p-value indicates the probability that the median for each crop is different between marketing channels (*** p<0.01, ** p<0.05, * p<0.1, Kruskal-Wallis test). n indicates the number of parcels for which the indicators (TFI) have been calculated. The colored boxes indicate the second and third quartiles, with the median represented as a vertical bar within them. The whiskers indicate the largest values which are not farther than 1.5 times the interquartile distance from the boxes. Outliers, which are individual points beyond the whiskers, are not plotted in order to improve the reading of the p-values on the figures.

Figure 3. Yields (log-transformed), by marketing channel and crop.

Distribution of yields for the seven crops and four marketing channels. The p-value indicates the probability that the median for each crop is different between marketing channels (*** p<0.01, ** p<0.05, * p<0.1, Kruskal-Wallis test). n indicates the number of parcels for which the indicators (yields) have been calculated. The colored boxes indicate the second and third quartiles with the median represented as a vertical bar within them. The whiskers indicate the largest values which are not farther than 1.5 times the interquartile distance from the boxes. Outliers, which are individual points beyond the whiskers, are not plotted in order to improve the reading of the p-values on the figures.

3 Conceptual and econometric framework

Farmers engaged in SFSCs are not randomly assigned and often self-select to participate. SFSC participation may therefore be endogenous, due to unobserved or unidentified variable factors affecting farmer adoption of SFSC categories and correlated with synthetic pesticide use and crop yields.

In particular, farmers engaged in SFSCs exhibit non-economic motivations such as the political motivation of supporting alternative agriculture methods (Alkon, 2008; Beingessner and Fletcher, 2020; Schoolman et al., 2021), personal and philosophical motivations associated with changing individual life-work balance, as well as the desire to do something more meaningful (Bruce, 2019; Fleury et al., 2016; Ngo and Brklacich, 2014), motivations linked to the enjoyment of meeting and getting to know customers (Fielke and Bardsley, 2013; Montri et al., 2021) and environmental motivations resulting from ecological concerns (Fleury et al., 2016; Izumi et al., 2010; Leiper and Clarke-Sather, 2017; Newsome, 2020). In addition, farmers who are not primarily driven by economic goals are more likely to reduce their use of synthetic pesticides (Bakker et al., 2021; Chèze et al., 2020; Howley, 2015; Läpple and Rensburg, 2011; Stallman and James, 2015). Thus, we expect that market gardeners with non-economic motivations are more likely to implement reduced synthetic pesticide farming practices and adopt SFSCs.

Although the effect of SFSC participation is expected to be biased downward because synthetic pesticide use is estimated without taking account of farmers' motivations, it could be also biased upward without controlling for farmers' risk aversion in our regression model. Some studies argue that SFSCs are a risk management tool for farmers, providing them with additional marketing opportunities (Kim et al., 2014; Kneafsey et al., 2013; LeRoux et al., 2010; Paul, 2019; Uematsu and Mishra, 2016; Zhang et al., 2019). Synthetic pesticides are also conventionally considered as risk-reducing inputs, as they help farmers to protect their crops from pest and disease damage (Bontemps et al., 2021; Chèze et al., 2020; Serra et al., 2008). Risk averse producers have been found to be less likely to adopt organic or reduced synthetic pesticide farming practices, because they lead to greater variability in yield and cost (Bontemps et al., 2021; Chèze et al., 2020; Serra et al., 2008). We therefore expect that more risk averse market gardeners are less likely to implement reduced synthetic pesticide farming practices and more likely to adopt SFSCs. Unambiguously predicting the direction of omitted variable bias is therefore impossible due to the presence of many omitted variables whose effect on the dependent variable is not of the same sign (Basu, 2018).

Using ordinary least squares (OLS) regression to estimate the SFSC participation effect on synthetic pesticide use would result in an inconsistent estimation. To disentangle the pure effects of SFSC adoption, we adopted a multinomial endogenous treatment effect model proposed by Deb and Trivedi (2006). This two-stage model allows us to account for both self-selection and the interdependence of adoption decisions. In our model, the choice of marketing channel is the treatment, and synthetic pesticide use and yields are the observed outcome measures. In the first stage, the adoption decision is modelled by a mixed multinomial logit selection model. In the second stage, OLS is used with selectivity correction to estimate the impacts of SFSC participation on synthetic pesticide use and crop yields.

3.1 Multinomial endogenous treatment effects model

The multinomial endogenous treatment effects model involves two stages. In the first stage, a farmer makes their marketing decision from a set of four marketing channel alternatives. Following Deb and Trivedi (2006), let V_{ij}^{*} denote the indirect utility obtained by farmer *i* in choosing the j_{th} marketing decision, $j = 0,1,2,3$:

$$V_{ij}^{*} = z_i'\alpha_j + \sum_{j=1}^{J} \delta_{jk} l_{ik} + \varepsilon_{ij} \tag{1}$$

Where z_i is a vector of covariates with associated parameters, α_j; ε_{ij} are independently and identically distributed error terms; l_{ik} is the latent factor that includes unobserved characteristics common to farmer $i's$ treatment choice and the outcome variables, such as farmers' non-economic motivations and risk aversion. Let $j = 0$ denote the control group (farmers using only LFSCs) and we normalize the indirect utility function to zero for this base choice so that V_{ij}^{*} = 0. Since l_{ik} is not observed, we use the binary variables d_j to represent the observed farmers' marketing decisions. The d_j measures follow a mixed multinomial logit (MNL) structure and $d_i = (d_{i1} d_{i2}, \ldots, d_{ij})$. The probability function for the marketing choice is modelled by a mixed multinomial logit structure defined as:

$$\Pr(d_i | \, z_i l_i) = \frac{\exp(z_i'\alpha + l_{ij})}{1 + \sum_{k=1}^{J} \exp(z_i'\alpha_k + l_{ik})} \tag{2}$$

We note that the mixed multinomial logit model involves the independence of irrelevant alternatives, implying that the choice between any marketing category is independent of the occurrence of a new marketing option.

The equation for the expected outcomes (TFI and crop yields) in the second stage is:

$$E(y_i | d_i, x_i, l_i) = exp \left\{ x_i'\beta + \sum_{j=1}^{J} \gamma_j d_{ij} + \sum_{j=1}^{J} \lambda_j l_{ij} \right\} \tag{4}$$

Where γ_i is the synthetic pesticide outcome or crop yield outcome for farmer i and x_i represents exogeneous covariates with parameter vectors β. Parameters γ_j denote the treatment effects relative to the non-adopters. $E(y_i | d_i, x_i, l_i)$ is a function of the latent factors l_{ij} when the outcome variable is affected by unobservable variables that also affect the choice of marketing channel. When λ_j, the factor loading parameter, is positive (negative), treatment and outcome are positively (negatively) correlated with unobserved variables, that is, there is a positive (negative) selection. We assume that the outcome variables follow a normal distribution. The model was estimated using a Maximum Simulated Likelihood approach.

For a more robust identification, Deb and Trivedi (2006) recommend using as exclusion restrictions selection instruments that directly affect the selection variable but not the outcome variable. However, this is not strictly required here, as the parameters of the semi-structural model are, in principle, identified through the nonlinear functional form of the selection model. The instrument used was the distance between the farm operators' home and the nearest city of 20,000 or more inhabitants. Urban areas provide better conditions for SFSC development by offering opportunities to reach more consumers with higher purchasing power and skills. We expect that the distance to the nearest city with a population of 20,000 or more to have no influence on synthetic pesticide use. Note that we do not use this instrument variable (IV) for a more robust estimation of the effect of SFSCs on crop yields, because we guess that the proximity to urban areas is correlated with parcel yields.

There is no formal test for the validity of exclusion restrictions in a nonlinear setting (Deb and Trivedi, 2006). Following Di Falco, Veronesi and Yesuf (2011), we performed a simple falsification test where candidate IV may affect the SFSC alternatives but has no influence on synthetic pesticide use among the non-adopting farmers. Results show that the nearest distance to a city of 20,000 or more can be considered as a valid instrument: it is statistically significant in equations of the adoption of SFSC strategies (Table 1) but not in equations of synthetic pesticide use (Table A2 in the Appendix).

4 Results

We present the results in two parts. In the first part, we present the determinants of the different strategies of SFSC involvement (DTC channels, DTR channels and a combination of DTC and DTR channels) (Table 1). In the second part, we discuss the effect of the different SFSC involvement strategies on the application of synthetic pesticides and crop yields (Table 2 and Table 3).

4.1 SFSC strategy determinants

Table 1 presents parameter estimates of the mixed multinomial logit model of the different SFSC channels. The reference category includes farmers involved only in LFSCs, against which the results are compared. We discuss the variables that are relevant to understand the environmental sustainability of farming practices.

Table 1. Mixed multinomial logit estimates of the determinants of adoption of each SFSC channel in market gardening (relative to adopting only LFSCs)

Variables	(1) DTC channels	(2) DTR channels	(3) DTC + DTR channels
Cabbage	-0.896***	-0.256	-0.751***
	(0.168)	(0.311)	(0.191)
Strawberries	0.0785	-0.365	-0.257
	(0.273)	(0.445)	(0.294)
Melons	0.550**	-0.158	0.406
	(0.247)	(0.393)	(0.258)
Leeks	-0.00570	0.355	0.255
	(0.197)	(0.336)	(0.213)
Lettuces	-0.721***	-0.152	-0.673***
	(0.210)	(0.353)	(0.231)
Tomatoes	-0.00810	-0.179	-0.177
	(0.250)	(0.383)	(0.258)
Log(Size)	-0.800***	-0.417***	-0.640***
	(0.0435)	(0.0663)	(0.0442)
ORG	0.419***	0.269	1.154***
	(0.144)	(0.218)	(0.136)
DIVSPE	3.504***	1.635***	3.253***
	(0.223)	(0.327)	(0.237)
DIVACT	0.385*	0.515*	0.572***
	(0.200)	(0.276)	(0.203)
LABEL	-1.206***	-0.661	-0.854**
	(0.349)	(0.438)	(0.383)
PEST	0.382	0.489	-0.0974
	(0.282)	(0.368)	(0.338)
FEMALE	0.700***	-0.492*	-0.111
	(0.136)	(0.265)	(0.168)
HIGHSCHOOL	-0.180	-0.225	0.295**
	(0.134)	(0.219)	(0.138)
BACHELOR	0.434**	0.251	0.533**
	(0.199)	(0.305)	(0.209)
MASTER	-0.0943	0.130	0.370*
	(0.199)	(0.315)	(0.203)
AGE	-0.00874*	-0.00612	-0.0330***
	(0.00495)	(0.00756)	(0.00534)
DISTANCE	-0.0179***	-0.0252***	-0.0156***
	(0.00384)	(0.00711)	(0.00443)
Region fixed effects	Yes	Yes	Yes
Constant	1.717***	-0.237	1.931***
	(0.439)	(0.674)	(0.454)
Observations	4,740	4,740	4,740

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

As expected, farm size (Size) decreases, and having a more diversified production system (DIVSPE) increases the probability of farmers participating in DTC channels, DTR channels and a combination of DTC and DTR channels. Most studies in the literature show that farms marketing through SFSCs are smaller in size (Ahearn et al., 2018;

Bruce and Som Castellano, 2016; Farmer and Betz, 2016; Filippini et al., 2018) and use diversified farming systems (Ahearn et al., 2018; Benedek et al., 2018; Björklund et al., 2009). Being engaged in certified organic practices (ORG) increases the likelihood of marketing through DTC channels and through a combination of both DTC and DTR channels, but we find no evidence that this increases the probability of marketing through DTR channels. This finding is in line with studies showing that farmers who participate in SFSCs are more likely to use organic farming practices (Aubert and Enjolras, 2016; Corsi et al., 2018; Navarrete, 2009). Using quality labels (LABEL) has a negative effect on the probability of adoption of DTC channels and participating in a combination of DTC and DTR channels, but we find no evidence that it has an effect on selling through DTR channels. This result is consistent with Corsi et al (2018), who show that labels of origin may be better exploited in conventional channels.

4.2 Impact of SFSC strategies on synthetic pesticide use

Table 2 presents the estimates of the impact of the different SFSC involvement strategies on the application of synthetic pesticides (TFI) in vegetable production. Full models are available in Table A3 in the Appendix. Market gardeners who use only LFSCs are the reference group. The estimated coefficients on the marketing options and the coefficients associated with the latent factors (λ) for synthetic pesticide use are the main findings of interest.

Table 2. Second stage estimate of synthetic pesticide use (TFI)

VARIABLES	OLS Model (1) Log(TFI)	Multinomial endogenous treatment effect model (2) Log(TFI)
Marketing options		
DTC channels	-0.362***	-0.723***
	(0.0252)	(0.0614)
DTR channels	0.0180	0.0285
	(0.0412)	(0.0818)
DTC + DTR channels	-0.263***	-0.493***
	(0.0280)	(0.0730)
Selection terms		
λ_{DTC}		0.423***
		(0.067)
λ_{DTR}		-0.005
		(0.077)
$\lambda_{DTC+DTR}$		0.256***
		(0.084)
Constant	1.373***	1.602***
	(0.0752)	(0.0830)
Observations	4,740	4,740

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Results show that market gardeners who sell some of their vegetables through DTC channels use significantly fewer synthetic pesticides than those who produce only for LFSCs. All other things being equal, switching from marketing vegetables only in LFSCs to also marketing in DTC channels leads to a 72% reduction (± 6,1%) of synthetic pesticide use. We do not find evidence that farmers who sell some of their vegetables through DTR channels employ significantly fewer synthetic pesticides than those who sell only through LFSCs. The only exception is when farmers combine both DTR and DTC sales, but the reduction effect is lesser than when the SFSC strategy includes only DTC sales. All other things being equal, switching from marketing vegetables only in LFSCs to also selling them both in DTC and DTR channels leads to a 49.3% reduction of synthetic pesticide use (± 7,3%).

The coefficients of the latent factors (λ) capture the effects on synthetic pesticide use of unobserved characteristics linked to the choice of marketing strategies. Market gardeners engaged in DTC channels and both DTC and DTR channels have positive significant selectivity correction terms, while these terms are not significant for those engaged in the SFSC strategy involving only DTR sales. This suggests that unobserved variables increasing the likelihood of adoption of SFSC strategies are associated with a higher use of synthetic pesticides, which means that if selection effects were overlooked, the predicted decline of synthetic pesticides would be underestimated.

4.3 Impact of SFSC strategies on crop yields

Table 3 reports the estimates of the impact of different SFSC strategies on vegetable production yields. Full models are available in Table A4 in the Appendix. Note that this model runs with fewer observations due to missing information on crop yields.

Table 3. Second stage estimate of crop yields

	OLS Model	Multinomial endogenous treatment effect model
	(1)	(2)
VARIABLES	Log(Yields)	Log(Yields)
Marketing options		
DTC	-0.102***	-0.125
	(0.0318)	(0.114)
DTR	0.0297	0.0589
	(0.0491)	(0.0789)
DTC + DTR	-0.0264	-0.0541
	(0.0348)	(0.122)
Selection terms		
λ_{DTC}		0.026
		(0.118)
λ_{DTR}		-0.032
		(0.045)
$\lambda_{DTC+DTR}$		0.031
		(0.126)
Constant	3.510***	3.527***
	(0.0947)	(0.133)
Observations	3,880	3,880

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

We did not find evidence of farmer participation in different SFSC channels having a negative effect on crop yields. In addition, the coefficients of the latent factors (λ) capturing the effects on yields of unobserved characteristics linked to the choice of the different SFSC strategies are non-significant.

5 Discussion and conclusion

5.1 Main results

The major contribution of this article is to investigate the effect on synthetic pesticide use and crop yields of different strategies of farmer involvement in SFSCs, depending on the presence or absence of an intermediary. We demonstrate that the effect of SFSC involvement on synthetic pesticide use varies depending on the SFSC types. Farmers who sell some of their vegetables through DTC channels employ significantly fewer synthetic pesticides than those who sell only through LFSCs, while we find no evidence that farmers involved in DTR use significantly less synthetic pesticides. The only exception is when farmers combine both DTR and DTC sales, but the reduction effect is lesser than when the SFSC strategy includes only DTC sales. In addition, we did not find evidence that farmer participation in different SFSC strategies decreases crop yields. These results are consistent with Mount and Smither (2014) who show qualitatively that farmers engaged in DTR channels adopt farming practices that are close to those used in conventional markets.

The adoption of more sustainable farming practices is hampered by socio-economic, institutional and political constraints occurring at each level of the food chain (Boulestreau et al., 2021; Cowan and Gunby, 1996; Guichard et al., 2017; Magrini et al., 2016; Meynard et al., 2018; Togbé et al., 2012; Vanloqueren and Baret, 2008; Wilson and Tisdell, 2001). In particular, farming practices are strongly framed by the specifications of the marketing channels, which set prices and determine product types, assortments, and volumes as well as marketing standards. As in LFSCs, farmers who sell part of their vegetables through DTR channels face marketing specifications that lock them into intensive farming systems. They have to efficiently provide a large and regular supply of uniform products while complying with stringent marketing standards (Zwart and Wertheim-Heck, 2021). For instance, farmers may apply synthetic pesticides in order to meet high cosmetic standards imposed by retailer requirements and consumer preferences (Pimentel et al., 1993; Yue et al., 2009; Zakowski and Mace, 2022). In contrast, SFSC marketing requirements are less standardized, giving farmers room to implement more environmentally friendly farming practices (Bressoud, 2010; Lefèvre et al., 2020, 2020; Marechal and Spanu, 2010; Milford et al., 2021; Navarrete, 2009). For example, the adoption of pest- and disease-resistant crop varieties, which can significantly reduce reliance on synthetic pesticides, is faced with marketing constraints such as uncertainty regarding consumer preferences (Finger et al., 2022). Retailers and wholesalers prefer marketing well-established varieties due to the perceived low market opportunities of pest- and disease-resistant crop varieties (Finger et al., 2022; Zhang et al., 2019). In contrast, farmers engaged in DTC channels are more likely to adopt these varieties, because they are not constrained by retailer preferences/demands and can ensure stable marketing conditions by communicating their product characteristics with customers (Finger et al., 2022; Zhang et al., 2019).

The development of more environmentally friendly farming practices depends on farmers' capacity to be economically competitive (Crowder and Reganold, 2015; Reganold and Wachter, 2016; Rosa-Schleich et al., 2019;

Sutherland et al., 2012). Both DTC and DTR channels can offer farmers economic benefits to outperform the disadvantages of yield losses that could be associated with the implementation of these alternative farming practices. A majority of consumers are willing to pay a premium for local food, and some studies show that this figure could be even higher in DTR channels because they are more conveniently located and offer complementary food products (Dunne et al., 2011; Richards et al., 2017). Farmers engaged in DTC channels prioritize more personal and meaningful connections with their consumers based on shared goals and values. This closer connection in DTC channels makes the tangible and intangible attributes of their products easier to recognize and allows farmers to command a price premium (Mount, 2012; Sundkvist et al., 2005; Verhaegen and Van Huylenbroeck, 2001). These closer interactions can even be considered as a substitute for organic certification, offering farmers a premium without the financial, administrative and time requirements of organic certification (Dabbert et al., 2014; Flaten et al., 2010; González-Azcárate et al., 2022; Higgins et al., 2008; Veldstra et al., 2014). There is no particular SFSC strategy that works best for farmers and that could better help them to make their alternative farming financially viable (Chiaverina et al., 2023). However, the large size and primarily economic motivations of farmers involved in DTR channels limits their capacity to deliver the set of intangible qualities associated with local food and therefore their ability to capture a premium (Mount, 2012; Mount and Smither, 2014; Rosol and Barbosa, 2021).

Farmers' decision-making on pest management methods may also depend on decisions made on neighboring farms (Bakker et al., 2021; Läpple and Kelley, 2015; Stallman and James, 2015). The more environmentally friendly farming practices associated with DTC channels may also be explained by their social dimension; offering farmers the opportunity to connect with each other (Chiffoleau et al., 2016; Lamine et al., 2009; Marechal and Spanu, 2010; Zoll et al., 2021). By favoring the exchange of knowledge and the sharing of alternative values, DTC channels promote the implementation of new practices and solutions and keep farmers' motivation high (Chiffoleau et al., 2016; Lamine et al., 2009; Marechal and Spanu, 2010; Zoll et al., 2021). An example of this is the French network label "Welcome to the farm", which brings together more than 4,500 farmers involved in DTC channels and provides support and advice from Chamber of Agriculture advisors, as well as opportunities for experience sharing among farmers.

The latent factors confirm that the multinomial endogenous treatment effect model is appropriate for analyzing the effect of SFSC participation on farmers' synthetic pesticide use. Synthetic pesticide use of market gardeners engaged in DTC channels and in a combination of DTC and DTR channels is upwardly biased, meaning that there are unobserved factors pushing farmers to apply more synthetic pesticides. If selectivity effects were improperly overlooked, the predicted decline of synthetic pesticide use would have been underestimated. This result might be surprising, as we expected farmers involved in SFSCs to have unobserved attributes, such as a stronger sense of environmental responsibility, driving them to reduce their application of synthetic pesticides. However, some studies find that farmers participating in SFSCs do not necessarily display higher environmental awareness (Schoolman et al., 2021; Tregear, 2011), despite the fact that others find the opposite (Izumi et al., 2010; Leiper and Clarke-Sather, 2017). In addition, predicting the direction of omitted variable bias is difficult, due to the presence of many omitted variables whose effect on the dependent variable may be not of the same sign (Basu, 2018). For example, the effect of SFSC participation is expected to be both biased downward, because synthetic pesticide use is estimated without taking account of farmers' motivation, and biased upward, due to omitting farmers' risk aversion in our regression model.

5.2 Limitations

Two issues that deserve discussion are those of the internal and external validity of the results. In terms of internal validity, information about marketing channels and our dependent variables (TFI and crop yields) are from two different databases from surveys carried out two years apart. Marketing channel information is from the 2020 agricultural census, and TFI and crop yields are from a national survey conducted in 2018 on the phytosanitary practices of representative market gardeners. Some market gardeners who indicated participation in SFSCs in 2020 may not have been involved in 2018, and vice-versa, which could bias our results.

In terms of external validity, these results are obviously context-specific and should not be generalized. They are specific to French vegetable production anchored in socio-political contexts and farming systems. In addition, this study relies on data during one year, which provides a static view of the effect of SFSC participation on synthetic pesticide use. Although Schoolman (2019) shows that an increase in the strength of local food systems has been associated with a decrease in spending on synthetic pesticides in the US, the magnitude of this negative relationship has decreased over time. One explanation is that key local food stakeholders (e.g., producers, consumers) have placed greater priority over time on product freshness and nutrition and supporting small farmers rather than on low-input farming practices (Schoolman, 2019). More research is needed to find out whether the effect of SFSC participation on the use of synthetic pesticides has varied over time, in what direction and for what reasons.

5.3 Policy implications

Nevertheless, this study provides some clues indicating that public support of DTC channels can be a lever to overcome socio-economic constraints that inhibit the reduction of pesticide use and the development of alternative practices (Hu, 2020; Nagesh et al., 2023). The absence of a downward trend in the use of synthetic pesticides, despite substantial policy efforts made by the French government, is partly due to a lack of awareness of these socio-economic impediments by agricultural policies (Guichard et al., 2017; Guyomard et al., 2020; Hossard et al., 2017; Lamichhane et al., 2016). The performance of EU agri-environmental schemes has also been questioned, because they have failed to drive the necessary cultural changes to sustainably embed more environmentally sustainable farming practices within farming communities (Burton and Paragahawewa, 2011; de Snoo et al., 2013; Kleijn et al., 2006; Wilson et al., 2007).

In France, both financial measures and legal instruments exist to support farmers engaged in DTC channels and steer them more closely to greater sustainability. These measures come from a variety of levels, including European, national and local levels. The 2013 EU common agricultural policy reform made SFSCs and local markets an explicit element of the EU's rural development policy for 2014-2020 (European Parliament, 2016). Several measures have been designed to develop SFSCs including investments in facilities for selling and processing agricultural products, setting up of producer groups and organizations, quality schemes, knowledge transfer, and training and advisory services. However, these measures have supported various types of SFSCs and local markets, independently of their sustainability potential. The definition of SFSCs and local markets at the French and European levels refers only to the number of intermediaries and geographical proximity, which is not a sufficient guarantee of sustainability (Kapała, 2022). Consequently, financial measures intended to support SFSCs should include in their eligibility criteria or payment intensity, requirements on environmentally friendly production methods, as well as other sustainability criteria. In addition, programs supporting SFSCs should be better evaluated in order to improve their effectiveness.

We show that uncertified organic market gardeners engaged in DTC channels use significantly fewer synthetic pesticides, which confirms that the closer interactions between farmers and consumers could be considered as a substitute for the organic certification label. We also find that organic certified farmers are more likely to be involved in DTC channels. These results demonstrate that promoting SFSCs does not necessarily undermine programs aimed at promoting certified organic farming, as claimed by Chen et al (2019). The EU Farm to Fork (F2F) strategy has set a target of having 25% of EU agricultural land under organic farming by 2030, from the current level of under 10%. To reach this ambitious goal, organic production policy in the EU provides small-scale and SFSC farmers better-targeted support (*Regulation (EU) 2018/848*, n.d.). Our results highlight that organic farming policies should better encourage DTC rather than DTR channels, because they offer farmers more opportunities and autonomy to implement ecologically sound practices. Flaten et al. (2010) argue that reducing the number of farmers renouncing organic certification is a more efficient strategy to reach organic production goals than attracting newcomers. Further research is needed to understand the role of an organic third-party certification in SFSCs. Some studies show that organic certification mainly benefits large farms with primarily economic motivations, which may lead to a deeper conventionalization of SFSCs (González-Azcárate et al., 2022; Higgins et al., 2008).

In March 2023, the French government launched a €200 million sovereignty plan, with the goal of increasing fruit and vegetable production and making it more sustainable. In particular, this plan gives more financial aid to the Territorial Food Projects (PAT) established by France's 2014 Law for the Future of Agriculture, Food and Forestry. These PATs have been mainly identified in the fruit and vegetable sectors and support territorialized food systems, SFSCs and all forms of quality and environmentally friendly agriculture through a wide range of actions implemented at the local level (Darrot et al., 2019). Some studies have questioned the practical contribution of SFSCs to food security, because farms engaged in SFSCs are smaller in size and hardly able to scale-up and move beyond their niche level (Cerrada-Serra et al., 2018; Deppermann et al., 2018; Lutz and Schachinger, 2013; Sundkvist et al., 2005). Although we do not find evidence that SFSC participation decreases crop yields, lack of evidence does not prove that the effect does not exist. In addition, high local food self-sufficiency is constrained by seasonality and can make food supply more vulnerable to production failures, such as climatic fluctuations or disease outbreaks (Sundkvist et al., 2005). However, food security is not only a matter of self-sufficiency and scale, but covers a wide range of challenges within the food system (Kirwan and Maye, 2013). Policies promoting DTC channels have a part to play in food security by favoring the adoption of more environmentally friendly practices in addition to fostering the resilience of the food system (Smith et al., 2016; Thilmany et al., 2021) and retaining domestic production (Kirwan and Maye, 2013).

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