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

Pierre Chiaverina<sup>1,2</sup>, Sophie Drogué<sup>1</sup> and Florence Jacquet<sup>1</sup>

**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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## 31 **1 Introduction**

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

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

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<sup>3</sup> 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).

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

48 Such inconclusiveness on the socio-economic and environmental impacts of SFSCs calls for further objective  
49 research relying on strong theoretical grounding and quantitative rigor (Malak-Rawlikowska et al., 2019; Stickel and  
50 Deller, 2014). In particular, certain aspects of the environmental impact of SFSCs, such as the use of synthetic  
51 pesticides by participating farmers, have received little research attention. Only a few studies conducted in the US  
52 and Asia examine the impact of SFSC participation on the use of synthetic pesticides and report lower synthetic  
53 pesticide use by farmers involved in SFSCs (Lee et al., 2020; Schoolman, 2019; Zhang et al., 2019; Zhang and Yu,  
54 2021).

55 Scientific studies have consistently revealed that pesticides are responsible for numerous harmful environmental  
56 and human health consequences (Carvalho, 2017; Geiger et al., 2010). Nevertheless, pesticide use has continued  
57 to increase globally (Zhang, 2018), and the numerous pesticide policies introduced by European member states  
58 have not been successful in reaching their pesticide usage reduction goals (Bjørnåvold et al., 2022; Hossard et al.,  
59 2017; Lamichhane et al., 2016; Möhring et al., 2020). Pesticide dependency is not only a technological issue for  
60 farmers, but also a socio-economic one involving multi-actors and multi-factors that policy frameworks should  
61 further consider in order to improve their effectiveness (Hu, 2020; Nagesh et al., 2023). Public support of SFSCs  
62 could be a lever to overcome some of the socio-economic obstacles to the adoption of pesticide alternatives. We  
63 identify in the literature three mechanisms of SFSCs that could have an effect on reducing synthetic pesticide use.

64 First, reducing synthetic pesticide use is not always an easy choice for farmers (Lee et al., 2019; Runhaar et al.,  
65 2017). The adoption of more sustainable farming practices is hampered by socio-economic, institutional and  
66 political constraints (e.g., product quality demands; economic constraints from marketing firms and regulations;  
67 lack of technical knowledge; unavailability of agroecological inputs occurring along the whole food value chain)  
68 (Boulestreau et al., 2021; Cowan and Gunby, 1996; Guichard et al., 2017; Jacquet et al., 2022; Magrini et al., 2016;  
69 Meynard et al., 2018; Togbé et al., 2012; Vanloqueren and Baret, 2008; Wilson and Tisdell, 2001). In particular,  
70 farming practices are strongly framed by the constraints of long food supply chains (LFSC), namely constraining  
71 farmers to produce large volumes of a few crops while complying with high marketing standards under price and  
72 competition pressure. Such specifications may encourage farmers to adopt, and lock them into, unsustainable  
73 farming practices (Burch et al., 2013; Lefèvre et al., 2020; Milford et al., 2021; Navarrete, 2009; Zwart and

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

82 Second, the development of more environmentally-friendly farming practices depends on the capacity of farmers  
83 to be economically competitive (Crowder and Reganold, 2015; Reganold and Wachter, 2016; Rosa-Schleich et al.,  
84 2019; Sutherland et al., 2012). Farmers involved in SFSCs can make their alternative farming practices financially  
85 viable by capturing a value-added premium generated by the reconnection between producer and consumer based  
86 on shared goals and values (Mount, 2012; Mount and Smither, 2014; Verhaegen and Van Huylenbroeck, 2001). The  
87 tangible and intangible qualities of their products (e.g., authenticity, safety and trust), which allow these farmers  
88 to command a price premium, are more easily recognized when the connection between farmers and consumers  
89 is closer (Mount, 2012; Verhaegen and Van Huylenbroeck, 2001). This price premium is crucial as it enables farmers  
90 to keep up with the disadvantages of potential yield losses associated with the adoption of reduced synthetic  
91 pesticide farming practices. The closer relationship between farmers and consumers can even be considered as a  
92 substitute for organic certification (Dabbert et al., 2014; Flaten et al., 2010; González-Azcárate et al., 2022; Higgins  
93 et al., 2008; Veldstra et al., 2014), as it builds up trust and reduces information asymmetry between farmers and  
94 consumers, thus convincing consumers that the products are as good as organic-certified alternatives. As such,  
95 farmers engaged in SFSCs can benefit from a higher premium than that fetched by certified organic products,  
96 without the financial, administrative and time burdens associated with certification (Onozaka and McFadden, 2011;  
97 Veldstra et al., 2014).

98 Finally, farmers' pest management decisions are strongly dependent on decisions made on neighboring farms,  
99 which highlights the importance of peer interactions among farmers (Bakker et al., 2021; Läßle and Kelley, 2015;  
100 Stallman and James, 2015). A positive experience with the adoption of alternative pest control methods (e.g.,  
101 reduced tillage) can be used as a model for farmers who belong to the same network and enhance their intentions  
102 to adopt the same methods (Bakker et al., 2021; Stallman and James, 2015). Participation in certain types of SFSCs,

103 such as farmers' markets and box schemes, can develop social interactions between farmers based on technical  
104 dialogue and support. Such learning connections among farmers developed through the market can provide them  
105 with shared values and experiences that can promote the consideration and practice of more sustainable farming  
106 (Chiffolleau, 2009; Chiffolleau et al., 2016; Jarosz, 2000; Lamine et al., 2009; Marechal and Spanu, 2010; Zoll et al.,  
107 2021).

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

120 However, DTR channels have the potential to reproduce the conventionalization seen in the organic product market  
121 by involving mainly large-scale producers with primarily economic motivations. Increased scale and competition in  
122 DTR channels can challenge the capacity of farmers to capture a premium and can force them to adopt more  
123 intensive farming practices (Ilbery and Maye, 2006; Mount, 2012; Mount and Smither, 2014; Rosol and Barbosa,  
124 2021). Indeed, farmers participating in DTR chains still have to comply with stringent marketing requirements that  
125 reward these intensive farming practices (Zwart and Wertheim-Heck, 2021). Mount and Smither (2014) show  
126 qualitatively that farmers participating in DTR chains adopt farming practices that are close to those used in LFSCs.  
127 Considering all SFSC types to be the same – particularly DTC and DTR channels – might therefore blur the effect of  
128 SFSCs on synthetic pesticide use because it combines what could be opposing results of these different SFSC types.

129 The objective of this paper is to investigate the effect on synthetic pesticide use of different strategies of SFSC  
130 involvement in vegetable production, depending on the presence or absence of an intermediary. In particular, we

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

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

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

## 152 **2 Data**

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

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<sup>4</sup> Strawberries and melons are classified as vegetables in this survey

156 survey, information is at the parcel or farm level, depending on the nature of the variable examined. In addition,  
157 we employ data from the 2020 French agricultural census, which provides complementary information about the  
158 socio-economic and production characteristics of vegetable farms. We match the data from the two surveys  
159 presented above, thanks to the business identification number assigned to each farm. We end up with a sample of  
160 4,740 market gardeners. Figure A1 in the Appendix provides the municipal location of the farms investigated.

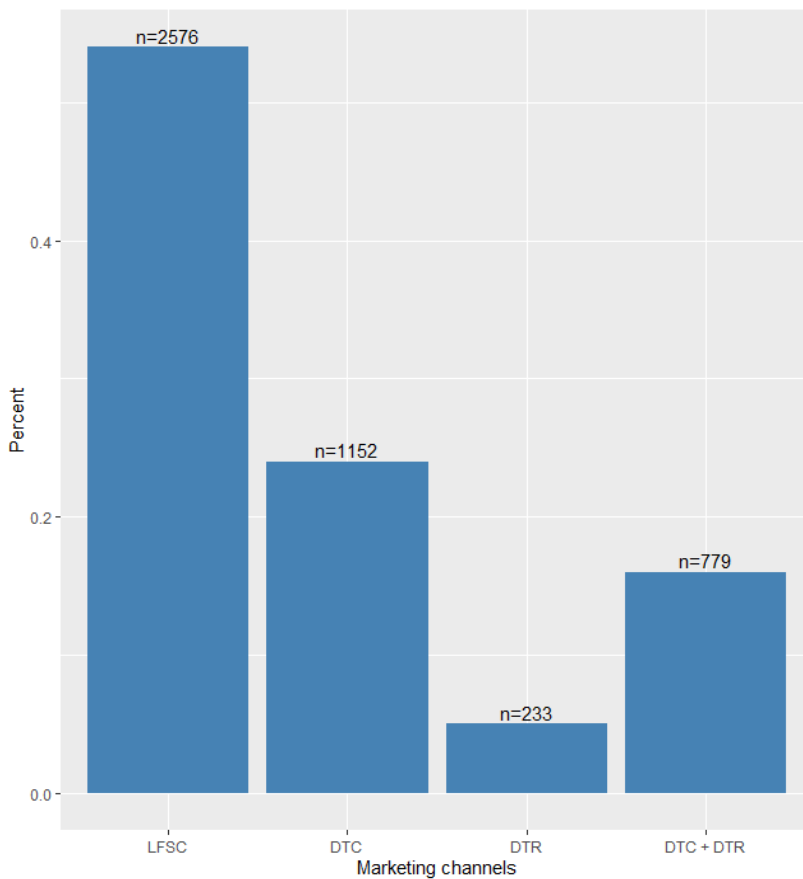
## 161 **2.1 Explanatory variables**

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

176

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<sup>5</sup> 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.



177

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

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

## 189 2.2 Dependent variables

190 The Treatment Frequency Index (TFI) is our dependent variable, measuring the use of synthetic pesticides on the  
 191 surveyed parcels. This index represents the ratio between the applied and recommended doses, considering the  
 192 area of the treated parcels (Pingault et al., 2009). For example, if the reference dose of an herbicide is spread

193 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  
194 of the TFI calculated for each treatment performed on the parcel during a crop season:

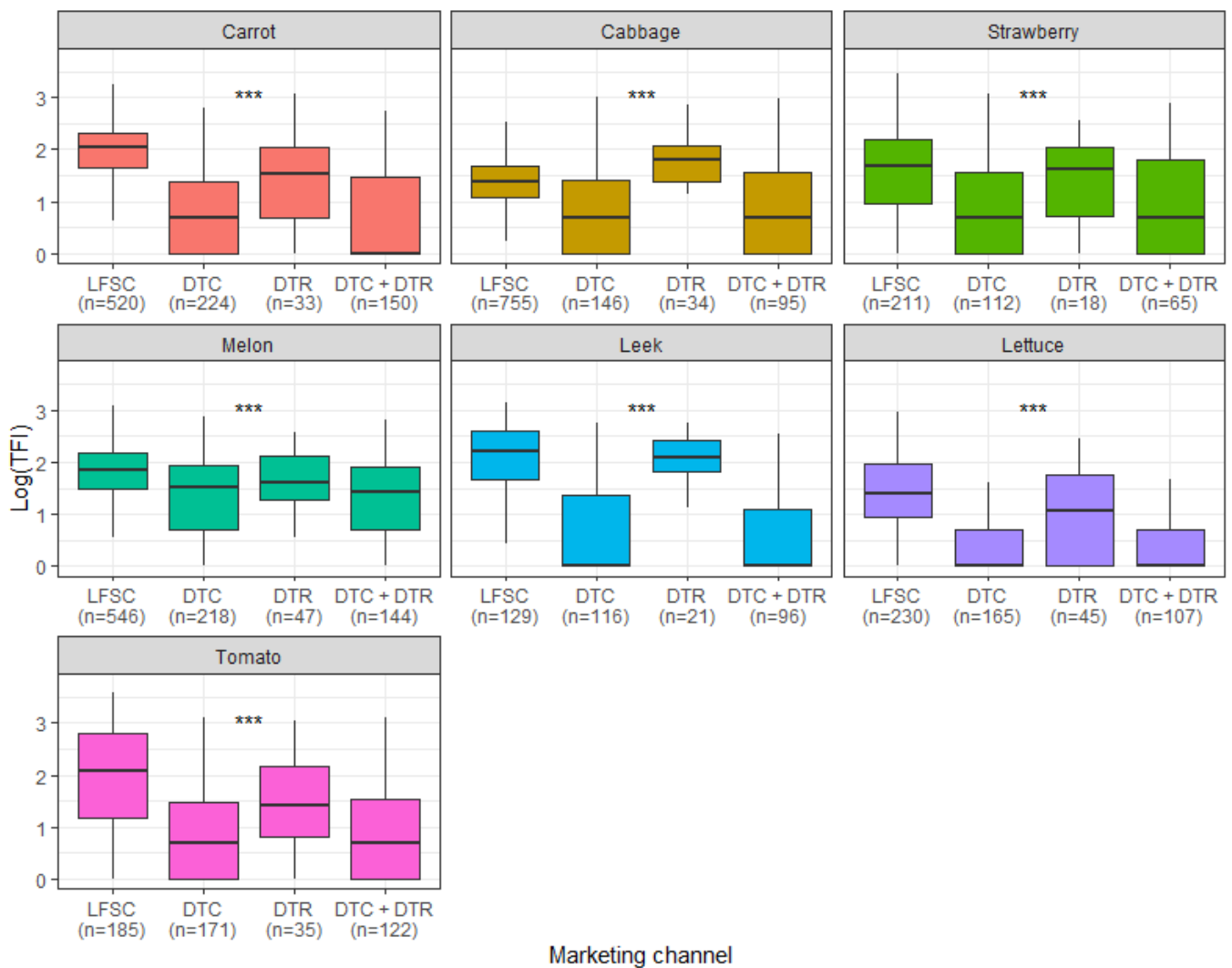
195 
$$TFI = \sum \frac{\text{applied dose}}{\text{reference dose}} * \frac{\text{treated area}}{\text{total area}}$$

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

206

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<sup>6</sup> We use the log-transformation of the TFI and yields to deal with skewness.

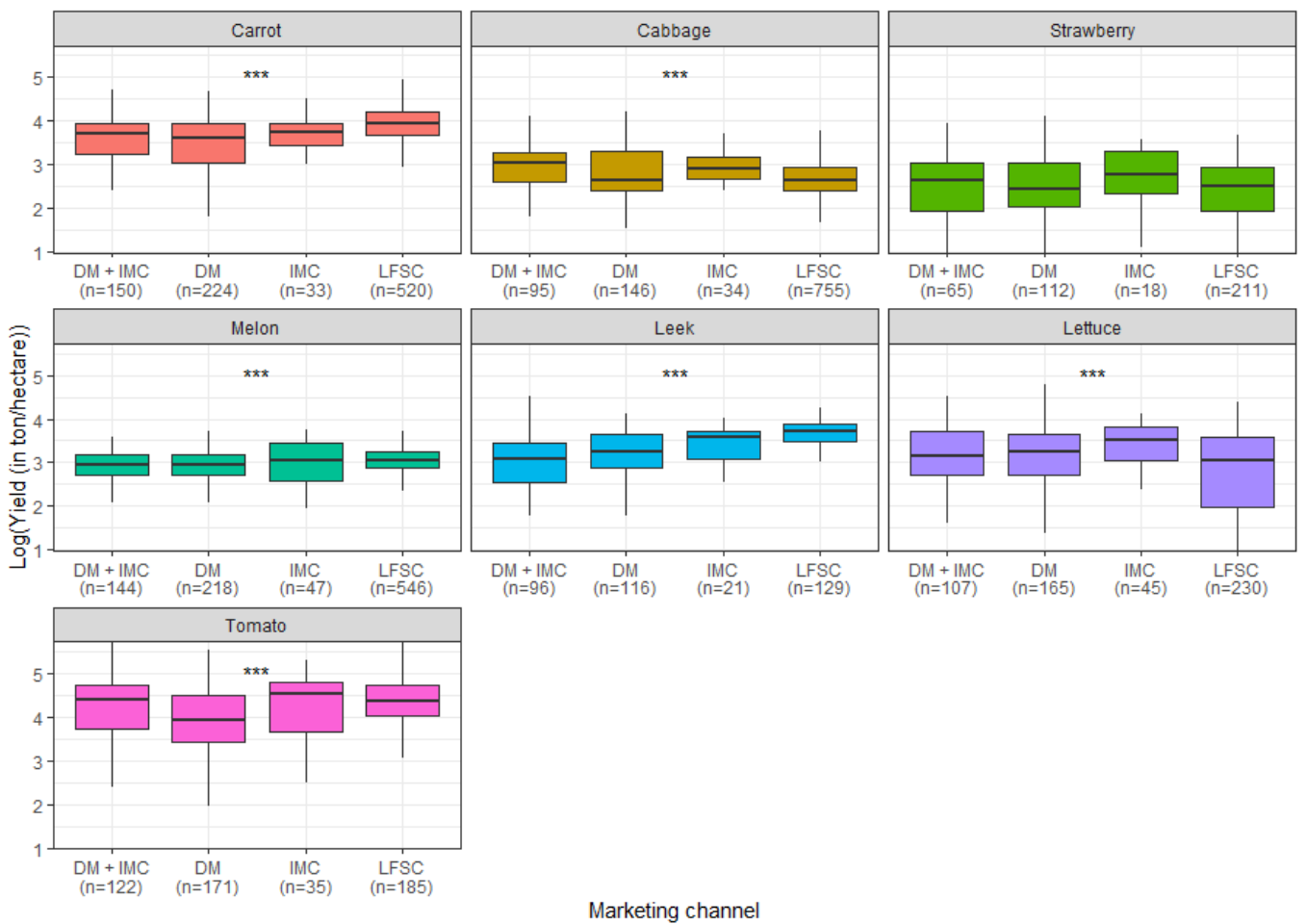


207

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

209 Distribution of the TFI for the seven crops and four marketing channels. The p-value indicates the probability that the median for each crop  
 210 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  
 211 the indicators (TFI) have been calculated. The colored boxes indicate the second and third quartiles, with the median represented as a vertical  
 212 bar within them. The whiskers indicate the largest values which are not farther than 1.5 times the interquartile distance from the boxes.  
 213 Outliers, which are individual points beyond the whiskers, are not plotted in order to improve the reading of the p-values on the figures.

214



215

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

217 Distribution of yields for the seven crops and four marketing channels. The p-value indicates the probability that the median for each crop is  
 218 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  
 219 indicators (yields) have been calculated. The colored boxes indicate the second and third quartiles with the median represented as a vertical  
 220 bar within them. The whiskers indicate the largest values which are not farther than 1.5 times the interquartile distance from the boxes.  
 221 Outliers, which are individual points beyond the whiskers, are not plotted in order to improve the reading of the p-values on the figures.

### 222 3 Conceptual and econometric framework

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

226 In particular, farmers engaged in SFSCs exhibit non-economic motivations such as the political motivation of  
 227 supporting alternative agriculture methods (Alkon, 2008; Beingessner and Fletcher, 2020; Schoolman et al., 2021),  
 228 personal and philosophical motivations associated with changing individual life-work balance, as well as the desire  
 229 to do something more meaningful (Bruce, 2019; Fleury et al., 2016; Ngo and Brklacich, 2014), motivations linked to

230 the enjoyment of meeting and getting to know customers (Fielke and Bardsley, 2013; Montri et al., 2021) and  
231 environmental motivations resulting from ecological concerns (Fleury et al., 2016; Izumi et al., 2010; Leiper and  
232 Clarke-Sather, 2017; Newsome, 2020). In addition, farmers who are not primarily driven by economic goals are  
233 more likely to reduce their use of synthetic pesticides (Bakker et al., 2021; Chèze et al., 2020; Howley, 2015; Läßle  
234 and Rensburg, 2011; Stallman and James, 2015). Thus, we expect that market gardeners with non-economic  
235 motivations are more likely to implement reduced synthetic pesticide farming practices and adopt SFSCs.

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

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

### 256 **3.1 Multinomial endogenous treatment effects model**

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

$$260 \quad V_{ij}^* = z_i' \alpha_j + \sum_{j=1}^J \delta_{jk} l_{ik} + \varepsilon_{ij} \quad (1)$$

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

$$268 \quad \Pr(d_i | z_i l_i) = \frac{\exp(z_i' \alpha + l_{ij})}{1 + \sum_{k=1}^J \exp(z_i' \alpha_k + l_{ik})} \quad (2)$$

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

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

$$272 \quad E(y_i | d_i, x_i, l_i) = \exp \left\{ x_i' \beta + \sum_{j=1}^J \gamma_j d_{ij} + \sum_{j=1}^J \lambda_j l_{ij} \right\} \quad (4)$$

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

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

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

## 295 **4 Results**

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

### 300 **4.1 SFSC strategy determinants**

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

304

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

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

307 Robust standard errors in parentheses  
 308 \*\*\* p<0.01, \*\* p<0.05, \* p<0.1  
 309

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

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

## 322 **4.2 Impact of SFSC strategies on synthetic pesticide use**

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

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

Robust standard errors in parentheses

\*\*\* p&lt;0.01, \*\* p&lt;0.05, \* p&lt;0.1

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

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

### 356 **4.3 Impact of SFSC strategies on crop yields**

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

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

Robust standard errors in parentheses

\*\*\* p&lt;0.01, \*\* p&lt;0.05, \* p&lt;0.1

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

## 381 5 Discussion and conclusion

### 382 5.1 Main results

383 The major contribution of this article is to investigate the effect on synthetic pesticide use and crop yields of  
384 different strategies of farmer involvement in SFSCs, depending on the presence or absence of an intermediary. We

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

393 The adoption of more sustainable farming practices is hampered by socio-economic, institutional and political  
394 constraints occurring at each level of the food chain (Boulestreau et al., 2021; Cowan and Gunby, 1996; Guichard  
395 et al., 2017; Magrini et al., 2016; Meynard et al., 2018; Togbé et al., 2012; Vanloqueren and Baret, 2008; Wilson  
396 and Tisdell, 2001). In particular, farming practices are strongly framed by the specifications of the marketing  
397 channels, which set prices and determine product types, assortments, and volumes as well as marketing standards.  
398 As in LFSCs, farmers who sell part of their vegetables through DTR channels face marketing specifications that lock  
399 them into intensive farming systems. They have to efficiently provide a large and regular supply of uniform products  
400 while complying with stringent marketing standards (Zwart and Wertheim-Heck, 2021). For instance, farmers may  
401 apply synthetic pesticides in order to meet high cosmetic standards imposed by retailer requirements and  
402 consumer preferences (Pimentel et al., 1993; Yue et al., 2009; Zakowski and Mace, 2022). In contrast, SFSC  
403 marketing requirements are less standardized, giving farmers room to implement more environmentally friendly  
404 farming practices (Bressoud, 2010; Lefèvre et al., 2020, 2020; Marechal and Spanu, 2010; Milford et al., 2021;  
405 Navarrete, 2009). For example, the adoption of pest- and disease-resistant crop varieties, which can significantly  
406 reduce reliance on synthetic pesticides, is faced with marketing constraints such as uncertainty regarding consumer  
407 preferences (Finger et al., 2022). Retailers and wholesalers prefer marketing well-established varieties due to the  
408 perceived low market opportunities of pest- and disease-resistant crop varieties (Finger et al., 2022; Zhang et al.,  
409 2019). In contrast, farmers engaged in DTC channels are more likely to adopt these varieties, because they are not  
410 constrained by retailer preferences/demands and can ensure stable marketing conditions by communicating their  
411 product characteristics with customers (Finger et al., 2022; Zhang et al., 2019).

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

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

429 Farmers' decision-making on pest management methods may also depend on decisions made on neighboring farms  
430 (Bakker et al., 2021; Läßle and Kelley, 2015; Stallman and James, 2015). The more environmentally friendly farming  
431 practices associated with DTC channels may also be explained by their social dimension; offering farmers the  
432 opportunity to connect with each other (Chiffolleau et al., 2016; Lamine et al., 2009; Marechal and Spanu, 2010;  
433 Zoll et al., 2021). By favoring the exchange of knowledge and the sharing of alternative values, DTC channels  
434 promote the implementation of new practices and solutions and keep farmers' motivation high (Chiffolleau et al.,  
435 2016; Lamine et al., 2009; Marechal and Spanu, 2010; Zoll et al., 2021). An example of this is the French network  
436 label "Welcome to the farm", which brings together more than 4,500 farmers involved in DTC channels and provides  
437 support and advice from Chamber of Agriculture advisors, as well as opportunities for experience sharing among  
438 farmers.

439 The latent factors confirm that the multinomial endogenous treatment effect model is appropriate for analyzing  
440 the effect of SFSC participation on farmers' synthetic pesticide use. Synthetic pesticide use of market gardeners  
441 engaged in DTC channels and in a combination of DTC and DTR channels is upwardly biased, meaning that there  
442 are unobserved factors pushing farmers to apply more synthetic pesticides. If selectivity effects were improperly

443 overlooked, the predicted decline of synthetic pesticide use would have been underestimated. This result might  
444 be surprising, as we expected farmers involved in SFSCs to have unobserved attributes, such as a stronger sense of  
445 environmental responsibility, driving them to reduce their application of synthetic pesticides. However, some  
446 studies find that farmers participating in SFSCs do not necessarily display higher environmental awareness  
447 (Schoolman et al., 2021; Tregear, 2011), despite the fact that others find the opposite (Izumi et al., 2010; Leiper and  
448 Clarke-Sather, 2017). In addition, predicting the direction of omitted variable bias is difficult, due to the presence  
449 of many omitted variables whose effect on the dependent variable may be not of the same sign (Basu, 2018). For  
450 example, the effect of SFSC participation is expected to be both biased downward, because synthetic pesticide use  
451 is estimated without taking account of farmers' motivation, and biased upward, due to omitting farmers' risk  
452 aversion in our regression model.

## 453 **5.2 Limitations**

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

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

## 469 **5.3 Policy implications**

470 Nevertheless, this study provides some clues indicating that public support of DTC channels can be a lever to  
471 overcome socio-economic constraints that inhibit the reduction of pesticide use and the development of alternative  
472 practices (Hu, 2020; Nagesh et al., 2023). The absence of a downward trend in the use of synthetic pesticides,  
473 despite substantial policy efforts made by the French government, is partly due to a lack of awareness of these  
474 socio-economic impediments by agricultural policies (Guichard et al., 2017; Guyomard et al., 2020; Hossard et al.,  
475 2017; Lamichhane et al., 2016). The performance of EU agri-environmental schemes has also been questioned,  
476 because they have failed to drive the necessary cultural changes to sustainably embed more environmentally  
477 sustainable farming practices within farming communities (Burton and Paragahawewa, 2011; de Snoo et al., 2013;  
478 Kleijn et al., 2006; Wilson et al., 2007).

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

491 We show that uncertified organic market gardeners engaged in DTC channels use significantly fewer synthetic  
492 pesticides, which confirms that the closer interactions between farmers and consumers could be considered as a  
493 substitute for the organic certification label. We also find that organic certified farmers are more likely to be  
494 involved in DTC channels. These results demonstrate that promoting SFSCs does not necessarily undermine  
495 programs aimed at promoting certified organic farming, as claimed by Chen et al (2019). The EU Farm to Fork (F2F)  
496 strategy has set a target of having 25% of EU agricultural land under organic farming by 2030, from the current level  
497 of under 10%. To reach this ambitious goal, organic production policy in the EU provides small-scale and SFSC  
498 farmers better-targeted support (*Regulation (EU) 2018/848*, n.d.). Our results highlight that organic farming policies

499 should better encourage DTC rather than DTR channels, because they offer farmers more opportunities and  
500 autonomy to implement ecologically sound practices. Flaten et al. (2010) argue that reducing the number of farmers  
501 renouncing organic certification is a more efficient strategy to reach organic production goals than attracting  
502 newcomers. Further research is needed to understand the role of an organic third-party certification in SFSCs. Some  
503 studies show that organic certification mainly benefits large farms with primarily economic motivations, which may  
504 lead to a deeper conventionalization of SFSCs (González-Azcárate et al., 2022; Higgins et al., 2008).

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

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526

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