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An Experimental Analysis of Pesticide Policies in Germany

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Abstract

Pesticides are one of the most important inputs in modern agriculture. However, intensive use of pesticides is also related to adverse effects on the environment and human health. While implementation of pesticide taxes with the intent to reduce pesticide applications has been widely discussed, green nudges are considered as innovative policy tools to foster environmental friendly behaviour. To date, little is known about the effects of these policy tools at the farm level. With this in mind, we use a business management game to investigate how a pesticide tax and a green nudge affect crop, tillage and pesticide decisions for a 'virtual' farm. Results from a sample of German agricultural students reveal that both policies are able to reduce the amount of pesticides applied. However, implementation of the pesticide tax also involves a substantial profit loss. Unlike in the green nudge treatment, participants under pesticide tax adjust their cropping and tillage strategies which could involve unintended ecological effects.

Keywords: pesticide policies, pesticide tax, green nudge, policy impact analysis, business management game

1 Introduction

Crop protection aims to prevent or reduce crop losses that can result from harmful pests such as weeds and pathogens (Oerke, 2006). Among other technologies, the application of pesticides has contributed considerably to the boost in agricultural productivity in recent decades (Sexton et al., 2007). Nowadays, pesticides are one of the most important inputs in modern agriculture (Tilman et al., 2002). In an extensive review, Cooper and Dobson (2007) summarise the many benefits that arise from pesticides in agricultural production. On the contrary, an excessive and inappropriate use of pesticides could also lead to negative external effects for the society that could, for example, be related to the contamination of ground and surface water, degradation of ecosystems and biodiversity, human health, food safety, and the evolution of pest resistance (Pimentel et al., 1992). Recently, concerns regarding the negative impacts of pesticides have grown rapidly and as result of the increasing public awareness, the use of pesticides has played a prominent role in public debate and policy agendas alike.

Reducing the harmful effects and risks from pesticides on human health and the environment has become a common goal albeit one of the most challenging environmental policy objectives in many countries (Skevas et al., 2012). According to the EU Directive on the sustainable use of pesticides, each member state is required to implement National Action Plans in order to achieve a sustainable use of pesticides (Directive 2009/128/EC). For instance, in Germany the so-called Pesticide Act (PflSchG, 2012) incorporates the EU directive into national legislation and regulates the application and purchase of pesticides. The German Pesticide Act also directly refers to the National Action Plan that aims to reduce risks that could result from the application of pesticides by 30 % until 2023 (Hommel, 2012). There is a broad set of policy options that could be designed to reduce pesticide use. In this regard, Oskam et al. (1997) distinguish between six domains of policy options: (1) command-and-control measures, (2) information, (3) technological and institutional change, (4) voluntary agreements, (5) private law instruments, and (6) economic instruments. However, overlaps between categories may also occur.

A growing body of literature states that economic instruments have become increasingly popular among policy makers (Vries and Hanley, 2016). Economic instruments are applied to change farmers' behaviour by setting financial incentives. In the light of the National Action Plans implemented in the European Union, there has been growing interest with respect to pesticide taxes in European countries. In a recent review, Böcker and Finger (2016) report that pesticide taxes are currently applied in Denmark, France, Norway, and Sweden while the implementation is also discussed in various other countries, such as Germany or the Netherlands. Generally, pesticide taxes are based on the polluter pays principle which ensures that the polluter (in this case the farmer) bears the costs of preventing, repairing or compensating for the environmental or health-related adverse effects that could arise from pesticide applications. Theoretically, an optimal designed tax fulfils these requirements by expressing the marginal net damage of pesticide applications (Lefebvre et al., 2015; Skevas et al., 2012). However, designing pesticide taxes is a complex task and estimates for external costs are rare (Pimentel et al., 1992). Thus far, empirical evidence on the effectiveness of pesticide taxes is rather mixed (Böcker and Finger, 2016). Some authors advocate the implementation of pesticide taxes arguing in the sense of the polluter pays principle (Pretty et al., 2001; Oskam et al., 1997). Finger et al. (2017) state that differentiated and well-defined pesticide taxes have a high potential to reduce risks from pesticide applications. However, they also note that pesticide taxes are ineffective in the short-run due to hording activities. Furthermore, the magnitude of the tax needs to be high which requires a re-distribution of tax revenues to the agricultural sector to prevent considerable income effects. An additional strand of research argues that farmers' demand for pesticides is rather inelastic, and thus, hampering the effectiveness of taxation schemes (Böcker and Finger, 2016; Skevas et al., 2012). For example, in Sweden and Denmark the introduction of a pesticide tax has not led to a substantial decline in pesticide sales and pesticides applications in absolute terms (SCB, 2017; Pedersen et al., 2015). Moreover, a solid ex-post evaluation that controls for confounding effects, such as the boost in cereal prices in the last decade, is usually lacking. It is not clear how pesticide applications would have developed without the implementation of taxes (Pedersen and Nielsen, 2017).

During the last decade, a new policy tool has captured the attention of policy makers. In addition to traditional policy tools, behavioural interventions in the form of nudging are increasingly being considered in different public policy contexts. According to Thaler and Sunstein (2008) who introduced the concept, a nudge is "any aspect of choice architecture that alters behavior in a predictable way without forbidding alternatives or significantly changing economic incentives" (Thaler and Sunstein, 2008 p. 8). Nudging takes advantage of various psychological biases in decision-making, such as inertia (Samuelson and Zeckhauser, 1988) or loss aversion (Kahneman et al., 1991), and can be implemented in wide variety of ways (Sunstein, 2014). Besides the provision of information (e.g. emphasising health consequences of smoking stated on cigarette boxes, cf. Hammond et al., 2006), the change of default options (e.g. changing the default setting of printers, from single-sided to double-sided printing, cf. Egebark and Ekström, 2016) or the use of social norms (e.g. comparing personal energy consumption to neighbours, cf. Allcott, 2011), the utilisation of priming is also part of the nudge toolkit. Priming is defined as the mental process by which the exposure to a stimulus, in other words a prime (e.g. words or images), activates associations in memory and thereby unconsciously influences a person's behaviour (Kahneman, 2011). Priming with colours is seen as particularly effective because people are exposed to colour in everyday life (Elliot et al., 2007). The colour red is most commonly associated with danger and risk as it is used to denote warnings or threats (e.g. warning signs or traffic light). Compared with complex information, the simplified depiction of information in the form of a traffic light is easier to understand (Olstad et al., 2015).

Nudging has become a popular policy tool in various domains, such as health economics (Arno and Thomas, 2016), tax compliance (Bobek et al., 2007) or environmental protection (Sunstein and Reisch, 2014). Recently, nudging is not only implemented to improve the welfare of the individual but also to reduce negative externalities in terms of environmental pollution, which is also referred to as green nudging (Schubert, 2017; Carlsson et al., 2018). The increasing interest in nudging raises the question if such behavioural interventions could also be implemented in an agri-environmental context to reduce negative external effects of agricultural production. So far, only a few studies have examined the effects of nudges in an agricultural setting. Chabé-Ferret et al. (2018) analyse a social comparison nudge on the water-saving behaviour of farmers. On average, nudging does not contribute to a change of water consumption patterns. However, they find that a nudge may increase water consumption of low level water users and decrease consumption of high level users. Peth et al. (2018) found that a nudge with information and pictures, as well as a nudge with an additional social comparison, can lead to an overall increase in compliance with water protection rules. Nevertheless, the authors point out that nudging in conjunction with a social comparison may aggravate already existing non-compliant behaviour. Kuhfuss et al. (2015) show that by the usage of social norms in nudging, farmers can be persuaded to participate in an agri-environmental scheme or continue participation in a scheme that has already begun. Another study by Czap et al. (2015) reveals that empathy nudges can strengthen environmental friendly behaviour of farmers by the appeal to put oneself in the shoes of a person who is affected by environmental pollution. Furthermore, Barnes et al. (2013) note that social comparison nudging may lead to higher adoption rates of water quality management techniques on farms.

Analysing the impact of agri-environmental policies, such as pesticide taxes or green nudging schemes prior to its implementation (ex-ante), and how farmers might respond to these policies is a challenging task. Thorough ex-ante policy analysis is beneficial for the society as it can prevent budgetary costs or unintended consequences from ill-designed polices. Recently, the application of so-called business management games for an experimental ex-ante analysis of agri-environmental policies has been established in applied economics (Mußhoff and Hirschauer, 2014). Business management games stem from the field of behavioural economics and can be classified as extra laboratory experiments (Charness et al., 2013). In business management games, participants deal with entrepreneurial decisions within a controlled environment framed to reflect complexities that are as realistic as required to address the particular research question (Keys and Wolfe, 1990). In contrast to classical laboratory experiments, involvement of actual decision makers as participants (such as farmers) and realistic framing enhance external validity (Charness et al., 2013). Moreover, costs can be kept low compared to field experiments (Burtless, 1995). Several studies have utilised business management games for agricultural policy impact assessments. For example, Holst et al. (2014) evaluate reward and penalty policies to foster the growing of flowering cover crops, while Dörschner and Mußhoff (2015) analyse farmers' environmental protection behaviour using species richness as an example. Furthermore, Buchholz et al. (2016) investigate different policy instruments for reducing irrigation water, Hermann et al. (2017) study policy options to enhance carbon sequestration in agricultural soils, and Peth et al. (2018) compare the effects of different nudge interventions on farmers' compliance behaviour with water protection rules.

Although the implementation of pesticide taxes has been widely discussed, there is only limited evidence on how individual farmers might respond at the farm-level (Skevas et al., 2012). To the best of our knowledge there is no experimental analysis of pesticide taxes to reduce pesticide applications. Furthermore, there is limited evidence how green nudges can be applied in an agricultural context. In particular, the concept of nudging as a means to lower pesticide applications has not yet been applied. Moreover, only a few studies compare the effects of taxes and nudges (Goldin and Lawson, 2016; Galle, 2014). Hence, there is still a need for empirical studies directly comparing the performance of nudge interventions with other types of policy instruments (Benartzi et al., 2017). Against this background, we seek to address the following research questions:

(1) Does the enforcement of a pesticide tax affect farmer's pesticide applications?

(2) Can nudging be applied to reduce farmers' pesticide applications?

(3) Which intervention is more effective in reducing pesticide applications – a tax or a nudge?

In order to analyse and compare the effects of a pesticide tax and a green nudge, we conduct a multi-period business management game with German agricultural students in which participants make production decisions, including the application of pesticides.

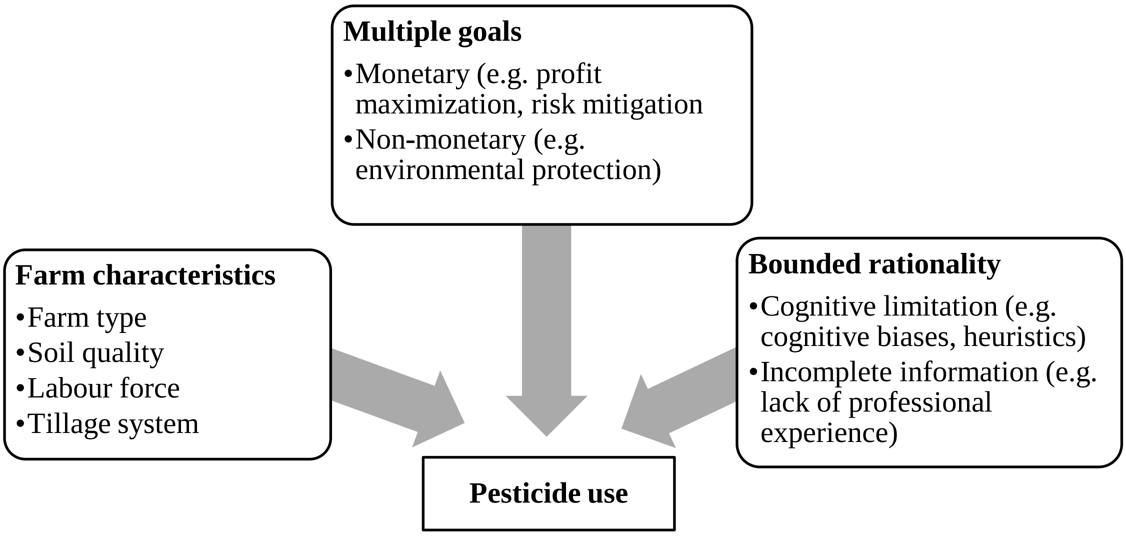
The remainder of the paper is organised as follows. Section 2 gives a brief overview of determinants influencing the use of pesticides. The experimental design is explained in Section 3. In Section 4, we describe our applied econometric approach. Results are presented and discussed in Section 5. The paper ends with our conclusions and prospects for future research in Section 6.

2 Additional Determinants of Farmers' Individual Pesticide Decisions

The effectiveness of agri-environmental policies depends on how the implemented policies will affect the behaviour of the targeted farmers (Primdahl et al., 2010). Studies dealing with impact assessment of agri-environmental policies predominately rely on normative rational choice models that are subject to rather restrictive assumptions, such as profit-maximizing behaviour (Gsottbauer and van den Bergh, 2011; Willock et al., 1999). However, there is evidence that decision makers in general – and farmers in particular – neither exhibit profit-maximizing behaviour nor act completely in accordance with the expected utility concept (Tversky and Kahneman, 1992; Bocquého et al., 2014; Quiggin, 1982). Likewise, decision makers could pursue multiple goals beyond profit-maximization and risk mitigation (Benz, 2009). Moreover, famers' decisions could be prone to bounded rationality (Camerer and Fehr, 2006; Simon, 1990). In addition, individual goals, attitudes and values may vary substantially among farmers (Maybery et al., 2005; Walder and Kantelhardt, 2018; Sulemana and James, 2014). As a consequence, farmers might respond differently to the same policies and in another way than predicted by normative theory.

The amount of pesticides used depends on a variety of determinants and varies across types of farms and among farmers. Figure 1 summarizes a selection of determinants that could affect farmers' pesticide strategies. Besides external factors, such as environmental conditions and pesticide policies applied that farmers cannot directly influence, we distinguish between the following determinants: farm characteristics, farmers' goals, knowledge and bounded rationality. Note, that the collection of determinants is not conclusive.

Figure 1. Determinants influencing individual pesticide use (authors' own illustration)



Farm characteristics

Analysing a dataset on chemical crop protection of 60 farms located in four districts of Northern Germany, Andert et al. (2015) find pronounced differences between districts and farms with regard to the pesticide use intensity. In a subsequent study, Andert et al. (2016) also show that farm type, legal form, soil quality and density of labour force influence the amount of pesticides used at the farm-level. Moreover, different soil management practices can require adjustments regarding pesticide strategies. For instance, conservation tillage may foster the proliferation of herbicides (Bürger et al., 2012; Melander et al., 2013). On the contrary, conventional tillage using plough can decrease the need for herbicide and fungicides (Andert et al., 2016; Freier et al., 2013).

Multiple goals

Farmers pursue monetary and non-monetary goals. In a study with Danish farmers, Pedersen et al. (2012) show that a distinction between two types of farmers can be made with regard to pesticide use. While costs and crop prices are more important for the economic-oriented farmer (profit maximization), the main goal for the yield-oriented farmer is the maximum yield regardless of the costs. In addition, Falconer and Hodge (2000) emphasize that farmers may prefer weed-free fields to preserve their professional pride and endure the consequence of higher pesticide use. Furthermore, risk attitudes towards operational risks and the health and environmental risks when applying pesticides can influence farmers' pesticide use decisions (Falconer and Hodge, 2000). In the literature, there is mixed evidence whether pesticides should be considered as a risk-increasing or risk-decreasing input (Lefebvre et al., 2015). Some authors argue that pesticides serve as an insurance against crop losses for risk-averse farmers (Mumford and Norton, 1984; Norgaard, 1976). In contrast, there is also evidence that pesticides can increase yield variability (Horowitz and Lichtenberg, 1994; Skevas et al., 2013; Pannell, 1991). In addition, farmers' decisions may be guided by attitudes towards health and environmental risks due to pesticide exposure (Lichtenberg and Zimmerman, 1999). In order to reduce these risks, famers are willing to accept foregone profits due to pesticide use below the economic optimum (Lefebvre et al., 2015).

Bounded rationality

Farmers' decision making may also be influenced by internal factors such as cognitive processes and habits. Behavioural economists describe these aspects as cognitive biases and heuristics (Tversky and Kahneman, 1974). Heuristics are simplified rules people use when quick and efficient decisions are required (Gigerenzer and Gaissmaier, 2011). They may work well but can also lead to systematic failures by ignoring available information. For example, in the case of the affect heuristic (influence of emotions on decisions or judgements, see Slovic et al., 2007) people tend to negatively relate the perceived benefit of something to the perceived risk (Alhakami and Slovic, 1994; Finucane et al., 2000). In case of pesticide use, this would mean that farmers link the high perceived benefits of crop protection products to low perceived risks for the environment and human health.

The reluctance to change the intensity of the pesticide application or to use alternatives may be influenced by the status quo bias. This cognitive bias describes the phenomenon that people tend to stick with previous made decisions. Any change from the current state will be perceived as a potential loss (Samuelson and Zeckhauser, 1988). For farmers, the presence of the status quo bias has been shown in the context of explaining inertia in investment decisions (Hermann et al., 2016). The status quo bias is strongly connected to Prospect Theory, according to which people value their gains and losses differently based on a reference point

(Kahneman and Tversky, 1979). In a recent study, Carpentier and Reboud (2018) point out that this reference situation may vary between farmers from the 'unprotected' crop to the 'protected' crop, which subsequently influences the actual pesticide application intensity. In addition, knowledge and professional experience in the field of chemical crop protection may affect farmers' pesticide strategies. For instance, Skevas et al. (2013) point out that lacking knowledge about alternative application practices can be one reason why demand for pesticides is rather inelastic. Furthermore, pesticide use may be influenced by advice through agricultural consultants and the professional experience of the farmer (Andert et al., 2015).

Given the variety of determinants that could affect individual pesticide strategies, it is not clear in advance how participants will respond to the pesticide tax and the green nudge in our business management game.

3 Experimental Design

The experiment consists of two parts. First, we conducted an incentive compatible, multi-period, one-person business management game. Secondly, socio-demographic characteristics of the participants were collected. Detailed experimental instructions are provided as supplemental information in the Appendix.

3.1 General Structure of the Business Management Game

In the business management game, participants managed a virtual cashcrop farm with 200 hectares of arable land. The game design is simple and easy for the participant to follow, yet complex enough to answer our research questions. Experiments with a more detailed framework would increasingly become more complex and time-consuming. This might overwhelm the participants and hinder them from completing the experiment successfully. Participants have to manage the farm for ten production periods. At the beginning of each period, three production decisions have to be made:

(1) Crop plan: All 200 ha of the arable land must be allocated to some combination of winter wheat and silage maize.

(2) Tillage strategy: For each crop, participants can use conventional or conservation tillage.

(3) Pesticide strategy: For each crop, participants can choose from three pesticide intensities.

Once the decisions have been made, the actual pesticide application rates are subject to environmental conditions occurring in the production period. In reality, farmers might normally decide first which crop to grow and their preferred tillage method, then adjust their pesticide strategy later in the cropping season when more information about infestation of weeds and pathogens in the field is available. To minimize game complexity, we assume simultaneous choice of crop and tillage plans and the pesticide strategy.

In the business management game, crop plans are subject to crop rotation constraints. Although these constraints are simplified, they allow us to model relevant relationships as needed which are appropriate for the analysis. In Germany, winter wheat and silage maize are the two major crops and account for 45 % of the total arable land (Statistisches Bundesamt, 2018). In accordance with good agricultural practices, the shares of winter wheat and silage maize in each period are constrained to 140 ha (70 %) or less in each case. The entire available land (200 ha) must be allocated to the two crops, so there is no option to set aside (or expand) arable land. For simplicity, the arable land is not divided into discrete plots, and all crop levels must be integers.

Product price developments follow an arithmetic Brownian motion (Dixit and Pindyck, 1994) starting from an initial value that is equal for all participants. Figure 1 depicts the potential development of product prices as shown to the participants. Starting from the prices in the current period, participants knew that product prices fall or rise by 1.0 €/dt for winter wheat and 0.2 €/dt for silage maize with a probability of 50 % in subsequent periods. Product prices for winter wheat and silage maize are not correlated for reasons of simplicity.

Figure 2. Potential product price development in the business management game (note: 1 dt = 100 kg)

	Realized price in period 0		**Uncertain price in period 1**	**Uncertain price in period 2**
				18.0 €/dt
		50 %	17.0 €/dt	
Winter wheat	16.0 €/dt			16.0 €/dt
		50 %	15.0 €/dt	
				14.0 €/dt
				2.9 €/dt
		50 %	2.7 €/dt	
Silage maize	2.5 €/dt			2.5 €/dt
		50 %	2.3 €/dt	
				2.1 €/dt

Crop yields are derived from comprehensive long-term field trials which were carried out in Germany (Pallutt et al., 2010; Jahn et al., 2010; LfL, several years). These field trials investigate the consequences of reduced pesticide applications using three different pesticide intensities: Local standard following situational extension advice (100 % pesticides), a selective reduction of the standard application rate by 25 % (75 % pesticides), and a blanket reduction of the standard application rate by 50 % (50 % pesticides). Pesticide treatments in the business management game are approximated by means of the so-called Treatment Frequency Index (TFI). In Germany, the TFI is used to quantify the intensity of chemical crop protection and comprises the number of pesticide treatments (fungicides, herbicides, insecticides and growth regulators) while considering the actual pesticide dosage relative to the maximum permitted dosage and treated area (Andert et al., 2015; Roßberg, 2013). For the 100 % pesticide strategy, TFI values are calibrated based on results from the 'network reference farms plant and protection' in Germany (Dachbrodt-Saaydeh et al., 2018) in order to reflect average farming conditions.

Crop yields are contingent on the chosen pesticide and tillage strategies. As the need for pesticide treatments might vary considerably according to the actual infestation of weeds and pathogens, we define three environmental states corresponding to unfavourable, normal and favourable conditions. Meanwhile, participants do not know which specific environmental conditions are going to follow. However, they are aware that unfavourable conditions occur with a probability of 20 %, normal conditions with a probability of 60 %, and favourable conditions with a probability of 20 %.

Table 1 reports crop yields and variable costs corresponding to the three pesticide strategies and three different environmental conditions. In general, winter wheat is more vulnerable to pests than silage maize and requires more pesticide treatments. Likewise, conservation tillage might facilitate proliferation of weeds in the long-run resulting in higher herbicide demands as compared to conventional tillage. Variable costs are based on reference calculations (KTBL, 2018). For the pesticide strategies with reduced pesticide intensity we assume additional costs of 10 €/ha for enhanced plant control and extension service. It should be noted that fixed costs associated with the application of pesticides are not a focus of this experiment. Instead, we model a short-term perspective assuming a fixed factor endowment.

In each production period, the virtual farm manager receives the total gross margin from crop production. A premium of 300 € per hectare is assumed to cover the fixed costs of farming.

Any remaining net profit is transferred to a virtual bank account. We assume that participants have access to interest-free loans for financing their variable costs. All products are sold at the end of each production period at the current market price. It is not possible to store the harvested crops. Pesticides are delivered just in time. After each period, participants receive a summary of the chosen crop plan, the realized profit, the realized TFI, the development of market prices, and the environmental conditions of the previous periods.

Before participants begin the business management game, they are given initial instructions (see Appendix). Following these instructions, control questions were provided to explicitly test if the participant had understood the instructions. These questions are designed in a way that correct answers are required in order to proceed. Before the actual business management game starts, participants have to pass a 'trial round,' which is not recorded but provides them an opportunity to become more familiar with the decision environment. These features improve the participant's understanding.

Table 1. Crop yields, variable costs, and treatment frequency index (TFI) according to tillage strategy and environmental conditions

Environmental conditions **Probability of occurrence**		**Unfavourable** **20 %**	**Normal** **60 %**	**Favourable** **20 %**
	---------- Winter wheat conventional tillage ----------			
100 % pesticides	Yield (dt/ha)	90	90	90
	Variable costs (€/ha)	1,030	1,000	970
	TFI	6.1	5.5	5.0
75 % pesticides	Yield (dt/ha)	85	87	89
	Variable costs (€/ha)	960	940	920
	TFI	4.5	4.1	3.8
50 % pesticides	Yield (dt/ha)	72	78	86
	Variable costs (€/ha)	890	880	870
	TFI	3.0	2.8	2.5
	---------- Winter wheat conservation tillage ----------			
100 % pesticides	Yield (dt/ha)	90	90	90
	Variable costs (€/ha)	1,010	980	950
	TFI	6.3	5.7	5.2
75 % pesticides	Yield (dt/ha)	84	86	88
	Variable costs (€/ha)	940	920	890
	TFI	4.7	4.3	3.9
50 % pesticides	Yield (dt/ha)	68	76	83
	Variable costs (€/ha)	870	850	840
	TFI	3.2	2.9	2.6
	---------- Silage maize conventional tillage ----------			
100 % pesticides	Yield (dt/ha)	500	500	500
	Variable costs (€/ha)	770	760	750
	TFI	2.0	1.9	1.7
75 % pesticides	Yield (dt/ha)	485	495	500
	Variable costs (€/ha)	745	740	730
	TFI	1.5	1.4	1.3
50 % pesticides	Yield (dt/ha)	470	490	500
	Variable costs (€/ha)	700	695	690
	TFI	1.0	0.9	0.8
	---------- Silage maize conservation tillage ----------			
100 % pesticides	Yield (dt/ha)	475	475	475
	Variable costs (€/ha)	800	785	780
	TFI	2.7	2.6	2.5
75 % pesticides	Yield (dt/ha)	420	470	475
	Variable costs (€/ha)	760	750	740
	TFI	2.0	1.9	1.8
50 % pesticides	Yield (dt/ha)	365	450	475
	Variable costs (€/ha)	710	700	695
	TFI	1.4	1.3	1.2

3.2 Policy Framework (Treatments)

At the beginning of the business management game, participants are randomly assigned to one of the three groups. Product price series and the development of the environmental conditions are identical for all participants and have been drawn in advance. This enables us to isolate the effects of the pesticide tax and the green nudge. In the first five production periods, the policy framework is identical for every participant. In the subsequent production periods (six through ten), the policy framework in the three groups becomes distinct:

Control group: The policy framework remains unchanged–no restriction on pesticides–over the entire duration of the business management game.

Pesticide tax treatment: We inform participants assigned to this treatment that the state will impose an additional tax on pesticides. The tax payment depends on the level of pesticides applied and amounts to 25 € per index point of the TFI. For winter wheat a pesticide strategy following local standards (100 % pesticides) and under normal environmental conditions, variable costs increase by 137.5 €/ha for instance. The design of the pesticide tax is set to approximate the tax burden in a recent proposal for a pesticide tax in Germany (Möckel et al., 2015). For reasons of simplicity, the pesticide tax in the business management game solely depends on the applied amount of pesticides in absolute terms. Thus, we do not account for varying toxicity levels of specific pesticides. In reality, a more differentiated tax scheme would be desirable (Finger et al., 2017; Kudsk et al., 2018).

Green nudge treatment: Participants in this treatment are informed that the state introduces new warning signs on plant protection products. All pesticides will be labelled with a traffic light depending on the toxicity level. In this business management game, the respective pesticide intensity is assigned to a traffic light colour for simplicity reasons (100 % = red, 75 % = yellow and 50 % = green).

3.3 Incentives for Well-Conceived Decisions

It is common practice to set incentives in economic experiments; former studies reveal that incentives generally improve decision making and result in better experimental findings (Guala, 2005; Camerer and Hogarth, 1999). To enhance motivation, each of the expected 100 participants received a representation allowance of 10 € if they completed the experiment. The average time to finish the experiment was approximately 30 minutes. In addition to the representation allowance, we provided additional success-oriented cash prizes of up to 600 €

in total to ensure incentive compatibility. Financial incentives were set in such a way that a trade-off was created between monetary objectives and socially desirable behaviour. First, prize money was awarded corresponding to the profits generated by the participants in the business management game. At the beginning of the experiment, participants were informed that three of the participants would be randomly drawn and those selected would receive 10 € for every 10,000 € of the average profit generated in the first five periods of the business management game. The price money awarded ranged from 77 € to 107 €. Rewarding the average profit is expected to balance pure risk-seeking and risk mitigation strategies, and should mitigate any loss of motivation that participants might feel after experiencing a low profit in early periods. Secondly, three participants had the chance to win a donation to a non-profit/charitable organization free of choice. Participants knew that the amount of the donation depends on the applied amount of pesticides in the business management game. The participant who realized the lowest average TFI over all periods received a donation of 100 €. The remaining two winners received a share of 100 € corresponding to the realized TFI. Donations awarded ranged from 58 € to 77 €. By means of the donation to a non-profit/charitable organization, we reward pro-environmental behaviour in the business management game. Depending on the preferences of the participants, the price money and donation rewarded can motivate the pursuit of economic or environmental objectives and the use of mixed strategies.

3.4 Sample Description

The experiment was conducted online from August to mid of November 2018 with a sample of German students. Participants were recruited among agricultural students at the University of Göttingen. The sample is comprised of 110 agricultural science students whose characteristics are summarised in Table 2. On average, the participants are 23 years old, with ages ranging from 18 to 35 years. The proportion of male students is 68 %. The sample consists of 68 % Bachelor students, while the remaining 32 % are on a Master's programme. 40 % of the participants have completed an agricultural training programme. The majority of students (65 %) have a family farm background. According to the self-assessed risk attitude scale following Dohmen et al. (2011), participants are on average slightly risk-seeking.

Table 2. Socio-demographic characteristics of the participants (N=110)

Characteristics	Mean	SD [a]	Min.	Max.
Age in years	22.5	2.2	18	35
Male students (%)	67.2	-	-	-
Share of Bachelor students (%)	67.2	-	-	-
Share with agricultural training (%)	40.0	-	-	-
Share of participants born on a farm (%)	64.5	-	-	-
Risk attitude [b]	5.8	1.8	2	10

[a] Standard deviation

[b] Self-assessed risk attitude: 0 (very risk averse) to 10 (very risk seeking)

4 Econometric Analysis

The participants' decisions regarding pesticide intensity are recorded as TFI for every period of the business management game. We apply an econometric model to control for the influence of single parameters in the business management game and other covariates of the questionnaire on pesticide application. In doing so, we can also separate confounding effects, such as learning effects during the experiment. The data set contains longitudinal data due to the recurring decisions made by individual participants, which can vary over the ten periods of the business management game. The questionnaires also provide time-invariant sociodemographic characteristics. Moreover, the dependent variable TFI is confined to positive real values ranging from 1.31 to 5.22, depending on the decisions and environmental conditions in the business management game. A Shapiro-Wilk test indicates that the TFI is not normally distributed (p-value < 0.001). To address these issues, we make use of the generalized additive models for location, scale and shape environment (GAMLSS). GAMLSS is a very general class of (semiparametric) regression models proposed by Rigby and Stasinopoulos (2005). GAMLSS features a large variety of response distributions for the dependent variable. Moreover, individual random intercepts can be incorporated as additive terms.

The model to estimate TFI can be formalized as follows. Let $y_{i\,TFI}$ denote TFI in period n applied by participant i for $i = 1, 2, \ldots,$ I and $n = 1, 2, \ldots, 10$. Previous analysis revealed that a Weibull distribution is the best choice for the dependent variable. A monotonic link function relates the mean μ of the dependent variable to the covariates, and is represented in Equation (1):

$$\log(\mu) = \eta = X\beta + Zy \qquad (1)$$

X denotes a known design matrix and β is the corresponding regression coefficient vector. In our analysis, Z is a design matrix of dummy variables, and y is the random intercept γ_i of participant i. The model is estimated by maximization of the penalized likelihood. Implementation is done using the GAMLSS package in R. For a detailed description of this model class and its full capabilities we refer to Rigby and Stasinopoulos (2005) and Stasinopoulos and Rigby (2007).

5 Results

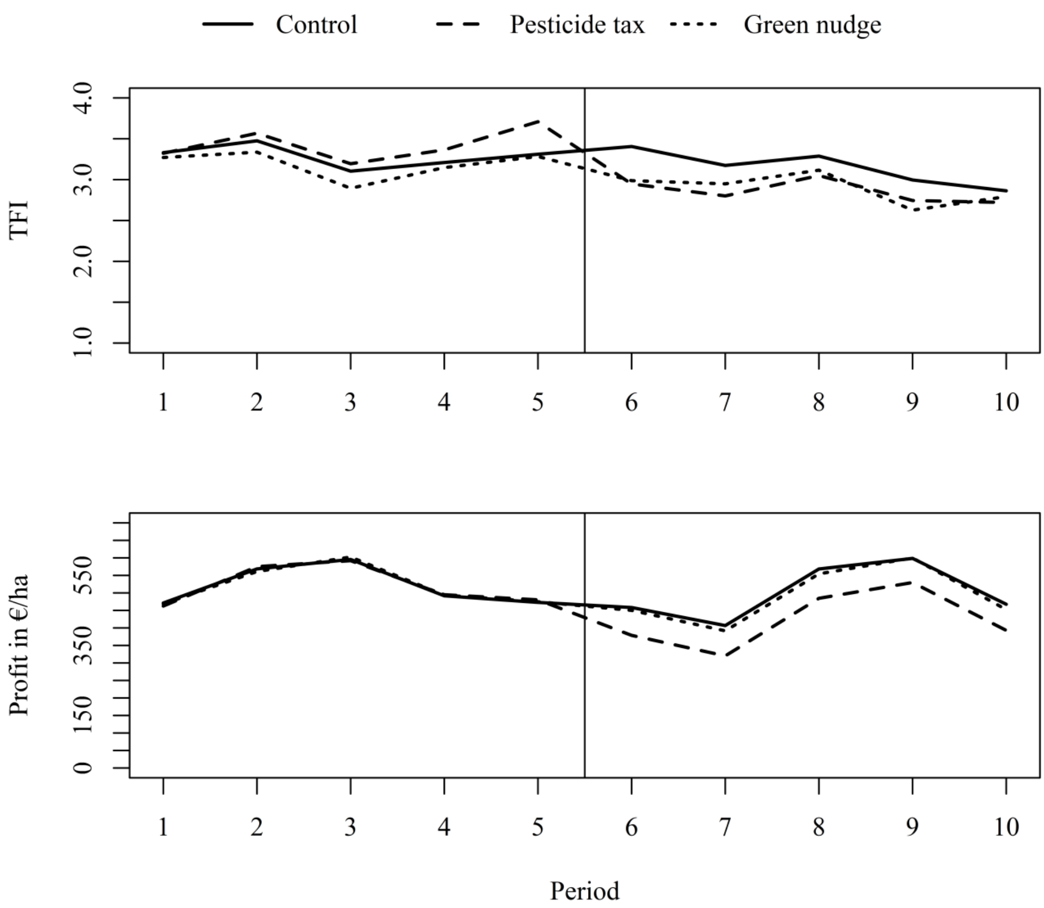
5.1 Descriptive Results

Pesticide intensity (TFI)

Table 3 shows the average farm-level TFI in the three groups in the business management game. We distinguish between periods 1-5 (before the treatment) and periods 6-10 (after the treatment). We first determine whether the TFI in the three groups is comparable before the treatment in periods 1-5. A Kruskal-Wallis test reveals a significant[1] difference in the average TFI between all groups in periods 1 to 5 (p-value ≤ 0.001). This finding might indicate that there could be confounding effects from behavioural differences not evenly distributed across groups. The upper panel in Figure 3 portrays the development of the farm-level TFI over periods. For all groups, a small downward trend of the TFI in the course of the business management game is apparent. We need to bear these findings in mind when contrasting the average TFI in periods 1-5 and 6-10 (within-subject comparison) and across groups for periods 6-10 (between subject comparison). By means of the within subject comparison we can account for different levels of the TFI between groups in periods 1-5. The between-subject comparison for periods 6-10 isolates possible effects from the downward trending TFI (Figure 3). In doing so, we are able to draw first conclusions about the effectiveness of the policy treatments.

[1] We explicitly refer to the term *significant* in the context of statistical analyses.

Figure 3. Mean values of TFI and profit in the business management game



For the control group, a Mann-Whitney-U test reveals no difference at the 5 % significance level in farm-level TFI between periods 1-5 and 6-10. In contrast, we observe a decline in the average TFI in the two groups with policy treatments in periods 6-10. In the pesticide tax treatment and nudge treatment, the TFIs in periods 6-10 are 0.58 and 0.29 index points lower corresponding to a relative decline by 16.91 % and 9.09 %, respectively. Both differences are statistically significant according to a Mann-Whitney-U test (p-values $\leq$ 0.001). Considering only periods 6-10, the TFI in the groups with pesticide tax and green nudge are nearly on the same level and amount to 2.85 and 2.89 (p-value = 0.672). Using the control group as reference (periods 6-10), the TFIs in the group with pesticide tax and nudge treatment decline by 0.30 (p-values $\leq$ 0.001) and 0.26 (p-values $\leq$ 0.001) index points resulting in relative reductions of 9.52 % and 8.25 %, albeit starting from a different level in periods 1-5.

Table 3. Mean (standard deviation) of farm-level and crop-specific pesticide intensities (TFI) according to treatment group [a]

Treatment group	Farm-level			Winter wheat			Silage maize		
	P 1-5	P 6-10	Dif.	P 1-5	P 6-10	Dif.	P 1-5	P 6-10	Dif.
Control	3.29 (0.67)	3.15 (0.74)	-0.14	4.60 (0.83)	4.45 (0.95)	-0.15	1.50 (0.47)	1.38 (0.42)	-0.12 [b]
Pesticide tax	3.43 (0.63)	2.85 (0.67)	**-0.58** [b]	4.70 (0.81)	3.98 (0.80)	**-0.72** [b]	1.60 (0.41)	1.36 (0.39)	-0.23 [b]
Green nudge	3.19 (0.65)	2.89 (0.68)	**-0.29** [b]	4.45 (0.80)	4.06 (0.84)	**-0.39** [b]	1.45 (0.41)	1.28 (0.33)	-0.17 [b]

[a] Bold values indicate significant differences in between-subject comparison for periods 6-10, control group serves as baseline (p-value ≤ 0.05).

[b] Significant difference in within-subject comparison before (periods 1-5) and after treatment (periods 6-10) (p-value ≤ 0.05).

Table 4. Shares of aggregated crop and tillage choice according to treatment group (%) [a]

Treatment group	Winter wheat			Silage maize			Conventional tillage			Conservation tillage		
	P 1-5	P 6-10	Dif.	P 1-5	P 6-10	Dif.	P 1-5	P 6-10	Dif.	P 1-5	P 6-10	Dif.
Control	58.07	56.61	-1.46	41.93	43.39	1.46	52.78	58.74	5.96	47.22	41.26	-5.96
Pesticide tax	59.54	54.66	-4.88 [b]	40.46	45.34 [b]	4.88 [b]	58.04	70.58	**12.54** [b]	41.96	29.42	**-12.54** [b]
Green nudge	57.86	56.56	-1.30	42.14	43.44	1.30	62.63	62.39	-0.24	37.37	37.61	0.24

[a] Bold values indicate significant differences in a between-subject comparison for periods 6-10, control group serves as baseline (p-value ≤ 0.05).

[b] Significant difference in a within-subject comparison before (periods 1-5) and after treatment (periods 6-10) (p-value ≤ 0.05).

Table 5. Mean and (standard deviation) of profit, revenue and variable costs in €/ha according to treatment group [a]

Treatment group	Profit			Revenue			Variable costs		
	P 1-5	P 6-10	Dif.	P 1-5	P 6-10	Dif.	P 1-5	P 6-10	Dif.
Control	519.98 (61.40)	499.89 (78.35)	-20.09 [b]	1,373.63 (77.64)	1,347.32 (92.84)	-26.31 [b]	853.65 (37.85)	847.42 (41.67)	-6.23
Pesticide tax	520.91 (62.51)	421.22 (82.71)	**-99.68** [b]	1,384.72 (77.50)	1,329.51 (96.19)	-55.21 [b]	863.81 (34.49)	908.28 (55.69)	**44.47** [b]
Green nudge	520.12 (61.68)	489.65 (83.31)	-30.47 [b]	1,371.63 (75.20)	1,328.21 (95.81)	**-43.42** [b]	851.51 (36.51)	838.56 (41.72)	**-13.00** [b]

[a] Bold values indicate significant differences in a between-subject comparison for periods 6-10, control group serves as baseline (p-value ≤ 0.05).

[b] Significant difference in a within-subject comparison before (periods 1-5) and after treatment (periods 6-10) (p-value ≤ 0

Moreover, we merge the three discrete pesticide intensities in the business management game which allows us to draw conclusions about differences in the crop-specific TFI for winter wheat and silage maize. In general, results for the crop-specific TFI follow those for the farm-level TFI (Table 3). The within-subject comparison (periods 1-5 vs. 6-10) reveals significant reductions in the average TFI for winter wheat in the pesticide tax and green nudge treatment groups. For silage maize, however, there is a significant decline at the 5 % significance level in all three groups. Compared to the periods 1-5, reductions in the crop specific pesticide intensities are most pronounced in the pesticide tax treatment for both winter wheat (-0.72) and silage maize (-0.23). On the contrary, the between-subject comparison in periods 6-10 reveals a significant decline in the TFI of winter wheat in the pesticide tax and green nudge group only.

Crop and tillage strategy

The policy treatments might not only have an influence on the TFI but also on the crop plan and the tillage strategy. Therefore, we analyse the aggregated decisions of participants on crop choice and the share of conventional and conservation tillage (Table 4). With regard to the selected crop acreages, we only see a slight but significant decrease in the average share of winter wheat in the pesticide tax group from periods 1-5 to periods 6-10 (p-value ≤ 0.008). Since it is not allowed to set aside land in the business management game, the reduction of winter wheat by 5 percentage points corresponds to an increase in the shares of silage maize by 5 percentage points. In the nudge treatment, we do not find a comparable effect.

According to a Kruskal-Wallis test, the share of conventional tillage differs significantly across groups in periods 1-5 before the treatment (p-value ≤ 0.001) which might be an indicator for varying preferences regarding soil management practices. Most strikingly, we only find a significant increase (decrease) in the share of conventional tillage (reduced tillage) in the pesticide tax treatment group both in the within-sample (p-value ≤ 0.001) and between-sample comparison (p-value ≤ 0.001). Also, the share of conventional tillage (conservation tillage) in periods 6-10 is significantly higher (lower) in the pesticide treatment than under the green nudge (p-value ≤ 0.022).

Economic impact

As product prices and environmental conditions are identical for all participants, the generated profits in the business management game reflect the economic consequences of the pesticide tax and the green nudge. The lower panel in Figure 3 visualises the development of profits over periods. Moreover, Table 5 reports average profits, revenues and variable costs according to treatment group for periods 1-5 and 6-10. In periods 1-5, there is almost no difference in profits between the three groups. In general, there is a slight and significant decline in revenues from period 1-5 to 6-10 in all groups. While the introduction of the pesticide tax leads to a decline of the average profit by 99.68 €/ha (p-value ≤ 0.001) profits in the nudge treatment group decrease by 30.47 €/ha in periods 6-10 (p-value ≤ 0.001). According to the between-subject comparison in periods 6-10, profits in the pesticide tax group and green nudge group are on average 78.67 €/ha and 10.24 €/ha lower than in the control group, respectively. However, only the difference for the pesticide tax is significant (p-value ≤ 0.001). On average, profits in the green nudge treatment are 68.43 €/ha above those generated under pesticide tax (p-value ≤ 0.001).

At the 5 % significance level, Kruskal-Wallis tests reveal no statistical difference in revenues between groups both in periods 1-5 (p-values = 0.127) and 6-10 p-value = 0.087). In contrast, a Mann-Whitney-U test reports a significant difference between the variable costs in the control and green nudge group of 19.11 €/ha in periods 6-10 (p-value = 0.047). Nevertheless, the results indicate that all selected cropping and pesticide decisions lead to comparable revenues. However, there is a slight but significant decline in revenues from period 1-5 to 6-10 in all groups.

Variable costs in the pesticide tax group are slightly higher than in the control and the green nudge group in periods 1-5 (bear in mind that TFI is also slightly higher). After enforcement of the pesticide tax, the within-subject comparison reveals a surge of variable costs of 44.47 €/ha (p-value ≤ 0.001). In contrast, variable costs in the nudge treatment decline by 13.00 €/ha (p-value ≤ 0.001). Compared to the control group in periods 6-10, variable costs in the group with pesticide tax significantly increase by 60.86 €/ha (p-value ≤ 0.001), while variable costs are 8.86 €/ha lower under the green nudge (p-value = 0.021).

5.2 Results of the Regression Models

We further investigate the decisions of the participants from the business management game by means of regression analysis validating the robustness of our results. Table 6 shows the results of the two regression models. In line with the within-subject comparisons, model I uses the farm-level TFI in periods 1 to 5 (before the treatment) as a reference, whereas the farm-level TFI of the control group in periods 6 to 10 is the reference in model II (between-subject comparison). Different results from both models might indicate that learning throughout the first five periods of the business management game might have confounded our earlier analysis of treatment effects. In addition to the variables from the business management game, such as product prices and environmental conditions, socio-demographic characteristics of the participants and dummy variables corresponding to the policy treatments are possible covariates. Variable selection is done by means of a search routine providing the best model fit according to the Akaike information criterion (AIC). The routine identified dummy variables for the two policy treatments (pesticide tax and green nudge), a dummy for favourable weather conditions, the product price for winter wheat and a dummy variable which refers to the periods in the business management game. For the final models, we manually incorporate additional socio-demographic variables to test whether there is an impact on TFI. For model I, we add a dummy for the control group to test if there is an effect on TFI without policy interventions in periods 6-10.

Table 6. Results of the GAMLSS models (Weibull distribution)

	Model I (periods 1-10)			Model II (periods 6-10 only)		
	Estimate	Exp (estimate)	p-value	Estimate	Exp (estimate)	p-value
Intercept	0.967	2.631	0.000	0.977	2.655	0.000
Dummy control [a]	0.011	1.011	0.545	-	-	-
Dummy pesticide tax	-0.111	0.895	0.000	-0.071	0.931	0.000
Dummy green nudge	-0.043	0.958	0.023	-0.073	0.929	0.000
Dummy favourable conditions	-0.089	0.915	0.000	-0.070	0.933	0.000
Product price winter wheat	0.015	1.016	0.017	0.017	1.017	0.015
Period	-0.007	0.993	0.013	-0.020	0.980	0.000
Age	0.004	1.004	0.023	0.006	1.006	0.015
Gender (female)	-0.089	0.915	0.000	-0.127	0.880	0.000
Agricultural training	0.000	1.000	0.978	-0.011	0.989	0.344
Family farm	0.015	1.015	0.097	0.044	1.045	0.000
Risk self-assessment	-0.005	0.995	0.056	-0.003	0.997	0.424
No. of observations	1,110			550		
Global deviance	1,543			642		
AIC	1,764			858		

[a] Periods 6-10 coded as reference.

Estimates in Table 6 are presented as (exponentiated) logs. The results of model I reveal that the enforcement of the pesticide tax and green nudge reduce the TFI by 10.5 % (1/0.895-1) and 4.2 % (1/0.958-1), respectively, compared to periods 1-5 before the treatments are applied. While the effects are statistically significant for the pesticide tax (p-values ≤ 0.001) and green nudge (p-values = 0.023) treatment, it is not the case in the control group. According to model II using decisions from the control group in periods 6-10 as reference, the TFI is reduced by 6.9 % in the pesticide tax treatment (p-value ≤ 0.001) and by 7.1 % in the green nudge treatment (p-value ≤ 0.001). Both models represent strong evidence that the policy treatments were effective in reducing the TFI. As the results for both models coincide, we are also able to rule out adverse effects from learning.

Moreover, both models reflect the relationship between the weather conditions and the applied pesticides in the business management game. The dummy variable for favourable environmental conditions separates changes in TFI related to environmental conditions in the business management game from those induced by the policy treatments. If environmental conditions are favourable, the TFI significantly declines by 8.5 % (model I) or 6.7 % (model II). In contrast, the TFI rises by 1.6 % (model I) or 1.7 % (model II) for an increase in the winter wheat price by 1 €/dt. The covariate 'period' captures the downward trend of the TFI (Figure 3). With every period, the TFI declines by 0.7 % (model I) or 2.0 % (model II).

Considering the socio-demographic characteristics, model I reveals significant effects for the covariates age and gender, whereas in model II the influence of a 'family farm background' is also significant at the 5 % significance level. With regard to age, we find an increase of the TFI of 0.4 % (model I) or 0.6 % (model II). For woman, the average TFI is lower by 8.5 % in model I and by 12.0 % in model II. In model II, having a 'family farm background' increases the TFI by 4.5 %.

6 Discussion and Conclusion

Besides the debate about the introduction of pesticide taxes to reduce negative externalities from intensive chemical crop protection, there is emerging research on green nudges to foster environmental friendly behaviour. Nevertheless, there is no experimental evidence how farmers might respond to these two policies at farm-level. With this in mind, the main goal of our experimental study was to investigate the effects of a pesticide tax and a green nudge (in form of traffic light labelling of pesticide intensities) on pesticide applications. We conducted a business management game in which a sample of German agricultural students managed a 'virtual' cash-crop farm and had to choose their cropping, tillage and pesticide strategies during several production periods while facing uncertain price and weather conditions.

The pesticide tax and green nudge are designed in a way to reduce pesticide intensities approximated by the chosen TFI in the business management game. We evaluate both polices in terms of their effectiveness, economic consequences at farm level and possible adjustments of crop rotation and tillage practices (Oskam et al., 1997; Falconer, 1998). A within-subject comparison reveals that the implementation of both policy measures reduced the TFI. According to our regression model, the TFI in the pesticide tax treatment and green nudge treatment declines by 10.5 % and 4.2 %, respectively. The economic consequences of both policies are assessed by the change in profits compared to the control group (between-subject comparison of means). On average, the introduction of the pesticide tax and green nudge results in a decline in profits by 79 €/ha and 10 €/ha, respectively. Furthermore, the analysis of the crop and tillage decisions reveals that participants with pesticide tax treatment tend to cultivate less winter wheat in favour of silage maize, which requires fewer pesticide treatments. In addition, the implementation of the pesticide tax leads to a shift from conservation to conventional tillage strategies involving a lower TFI. We do not find such adjustment effects in the green nudge group.

The pesticide tax increases the costs for pesticide applications, and thus, provides an economic incentive to adjust pesticide intensities. In contrast, nudging intends to influence the behaviour by altering the decision environment without economic incentives (Thaler and Sunstein, 2008). Traffic light labelling of pesticide strategies sends a signal to participants that high pesticide intensities coloured in red are less desirable from society's perspective. However, taxes could also be understood as a signal to consider negative externalities from crop protection, encouraging farmers to reduce pesticide applications (Andersen and Sprenger, 2000 pp. 42–43).

A further important implication from our results for the pesticide tax is that farmers' agronomic adjustments to reduce the tax burden could involve unintended ecological effects. For instance, conventional tillage exhibits a higher energy demand and is likely to increase the exposure of soil erosion (Montgomery, 2007; Holland, 2004). Additionally, cultivation of crops with low pesticide demands might increase and result in crop rotations with only a few crops. For example, the expansion of maize production is particularly criticised by the public in Germany (Linhart and Dhungel, 2013). These findings enhance understanding of pesticide policies and could be useful for policy makers.

The external validity of experimental approaches, as applied in this study, is limited to some extent (Roe and Just, 2009). We mitigate this drawback by means of a realistic framing of the decision situation. Nevertheless, we admit that economic reality is more complex than portrayed in the business simulation game. For instance, farmers can choose between a variety of pesticide products with different toxicity levels. Moreover, one might be tempted that the subject pool of students in our study may exacerbate generalisations about the response behaviour of farmers. However, this might not be the case for two reasons. First, we use students of agricultural sciences of which 40.0 % completed an agricultural training and 65.5 % grew up on farm, and are familiar with agricultural production decisions. Secondly, other studies have shown that students and farmers can respond in similar ways to policy measures. In an analysis of agri-environmental measures, Peth and Mußhoff (2018) compared decisions from students and farmers in a business management game. Their results showed that the direction of the response to policy treatments was similar for agricultural students and farmers. Only the magnitude of the treatment effect differed between the two samples. However, we are currently in the process of investigating the response behaviour of real farmers in a further study to validate the results of our experiment with students. Notwithstanding these limitations, business management games are a useful tool for ex ante policy impact analysis that can contribute to more efficient design of policies at the farm level. This holds particularly true for ‘smart’ policies that do not involve economic incentives, such as green nudges.

From our study, we cannot answer the question how pesticide taxes and green nudges would work as a combination. Future research should concentrate on analysing the impacts of a joint implementation of pesticide taxes and green nudges. Since nudges are often described as more cost-efficient than traditional policy instruments, such as taxes, it would be interesting to assess actual implementation costs of the green nudge described in our study. Knowing the costs for traffic light labelled packaging of plant production products would facilitate the comparison of the nudge with the tax regarding the impact per € or $ spend as proposed by Benartzi et al. (2017). Future experimental research should address the analysis of more differentiated pesticide taxes as advocated in the literature (Böcker and Finger, 2016).

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Appendix

Table A1. Results of the GAMLSS models (Normal distribution)

	Model I (periods 1-10)			Model II (periods 6-10 only)		
	Estimate	Exp (estimate)	p-value	Estimate	Exp (estimate)	p-value
Intercept	2.305	10.026	0.000	2.106	8.217	0.000
Dummy control	0.025	1.025	0.725	-	-	-
Dummy pesticide tax	-0.365	0.694	0.000	-0.227	0.797	0.000
Dummy green nudge	-0.148	0.862	0.040	-0.228	0.796	0.000
Dummy favourable conditions	-0.229	0.795	0.000	-0.151	0.860	0.005
Product price winter wheat	0.065	1.067	0.007	0.086	1.089	0.002
Period	-0.027	0.973	0.012	-0.067	0.935	0.000
Age	0.005	1.005	0.445	0.012	1.013	0.192
Gender	-0.204	0.815	0.000	-0.272	0.762	0.000
Agricultural training	-0.027	0.974	0.410	-0.034	0.966	0.426
Family farm	0.075	1.077	0.026	0.106	1.112	0.018
Risk self-assessment	-0.012	0.988	0.186	-0.012	0.988	0.317
No. of observations	1,110			550		
Global deviance	1,606			733		
AIC	1,818			926		

Instructions for the Business Management Game

You are responsible for running a farm with 200 cultivated hectares for a time period of 10 years (= 10 game periods).

At the beginning of each game period, you need to determine your cultivation program (decision 1), the varieties of different field crops and type of soil tillage on your fields (decision 2) as well as the intensity of application of plant protection products (decision 3).

The revenue you achieve is dependent on environmental variables such as pest and disease pressure as well as your soil tillage and plant protection intensity decisions. The scenario does not include a warehouse option meaning that the crops grown are automatically sold for the current market price at the end of each period, and plant protection products cannot be stored either. You source your plant protection products directly from your agricultural dealer. Revenues at the end of each period will be credited to your bank account.

At the beginning of the game your bank account balance is 50,000 €. If at any point during the game you overdraw your account, you can lend money interest-free from close relatives. As soon as you regain liquidity at the end of a production period, the capital you borrowed will automatically be paid back.

Decision 1: Determine the cultivation program

For the cultivation of the farmland, you can select from a choice of two field crops:

1. Winter wheat
2. Silage maize

The following cultivation standards are to be observed:

a. Winter wheat can be grown on at most 140 ha (70 %) of your land.
b. Silage maize can be grown on at most 140 ha (70 %) of your land.
c. All farmland must be cultivated. It is not allowed to set aside farmland.
d. It is only possible to cultivate integer hectares of farmland. For example, it is possible to cultivate 50 ha or 51 ha of winter wheat, but it is not possible to use 50.5 ha of farmland.

Decision 2: Choose the soil tillage program

For each field crop, you can choose from two soil tillage types:

1. Conventional ploughing
2. No-till cultivation

Please note that you can choose both tillage types for either crop in each period. This means, for example, you could choose to employ no-till cultivation on all of your winter wheat area, or place part of the area under no-till and the other part under conventional ploughing.

Decision 3: Choose the plant protection intensity

For each field crop, you can choose between three plant protection strategies:

1. Local standard (i.e. conventional) of quantity applied (100 % application intensity)
2. A selective reduction by 25 % of the local standard (75 % application intensity)
3. A blanket reduction by 50 % of the local standard (50 % application intensity)

Please note that you can choose all three plant protection strategies in each period. For example, you could choose to apply the local standard (i.e. 100 % application intensity) of plant protection product to 50 ha of your silage maize, while on the further 30 ha of silage maize you could employ 75 % of the standard application intensity.

Treatment Frequency Index

The applied amount of plant protection products will be displayed in a simplified form by the so-called Treatment Frequency Index (TFI). The Treatment Frequency Index is a measure of plant protection intensity which considers the number of products applied, i.e. fungicides, herbicides, insecticides and plant growth regulators, as well as the application rate and area of land. In the case of tank mixtures, each plant protection product is counted separately.

The Treatment Frequency Index per plant protection measure can be calculated as such: (applied quantity / max. allowed quantity) * (treated area / total area). The following examples serve to make the calculation procedure more clear:

a. The application of an herbicide to silage maize at the max. allowable application rate results in a TFI of 1.
b. The application of an herbicide to silage maize at the max. allowable rate on only a quarter of farmed area results in a TFI of 1*0.25 = 0.25.
c. A fungicide application to winter wheat at 80 % of the allowed application rate results in a TFI of 0.8.
d. Two herbicide treatments to silage maize each at 70 % of max. allowable application results in a TFI of 1*0.7 + 1*0.7 = 1.4
e. A tank mixture of fungicide and plant growth regulator applied to winter wheat both at 80 % of the max. allowable application rate results in a TFI of 0.8*1 + 0.8*1 = 1.6.

Various field experiments have shown that in the short term, with reduced application rates under favourable conditions (e.g. healthy soils, crop rotations, high-yielding varieties, favourable sowing period, and favourable weather conditions during seeding), reasonable yields can be achieved. Nevertheless, "keep in mind that an improper reduction of plant protection product application can lead to long-run problems such as increased weed pressure, the emergence of more persistent weed species and the development of resistances."

Yields, Variable Costs and Treatment Frequency Indices of the Production Methods

The yield per hectare depends on the pest and disease pressure in the given period. For simplification reasons, we do not consider the effects of previous crops. The occurring pest and disease pressure is unknown before the start of each period. However, you are aware that the likelihood of a "normal" pest and disease pressure situation is 60 %. The likelihood of experiencing high or low pest and disease pressure during a given period is 20 % each. The occurrence of high pest and disease pressure in a period results in the increase of the Treatment Frequency Index calculations for plant protection applications. Accordingly, a period with low pest and disease pressure leads to lower Treatment Frequency Index levels.

The following tables illustrate the relevant yield levels and variable costs (including the needed plant protection products) under different pest and disease pressure situations. The variable costs consist of costs associated with the cultivated crops and the tillage type, as well as the variable costs for plant protection products and their application.

With reduced plant protection application rates (75 % and 50 %), we estimate an additional expense of 10 €/ha for further stock control and additional consultation services.

Winter Wheat, Conventional Ploughing

Weather conditions Probability of occurrence		Unfavorable 20 %	Normal 60 %	Favorable 20 %
100 % Application Rate	Yield dt/ha Variable costs €/ha TFI	90 1030 6.1	90 1000 5.5	90 970 5.0
75 % Application Rate	Yield dt/ha Variable costs €/ha TFI	85 960 4.5	87 940 4.1	89 920 3.8
50 % Application Rate	Yield dt/ha Variable costs €/ha TFI	72 890 3.0	78 880 2.8	86 870 2.5

Winter wheat, No-till Cultivation

Weather conditions Probability of occurrence		Unfavorable 20 %	Normal 60 %	Favorable 20 %
100 % Application Rate	Yield dt/ha Variable costs €/ha TFI	90 1010 6.3	90 980 5.7	90 950 5.2
75 % Application Rate	Yield dt/ha Variable costs €/ha TFI	84 940 4.7	86 920 4.3	88 890 3.9
50 % Application Rate	Yield dt/ha Variable costs €/ha TFI	68 870 3.1	76 850 2.9	83 840 2.6

Silage Maize, Conventional Ploughing

Weather conditions Probability of occurrence		Unfavorable 20 %	Normal 60 %	Favorable 20 %
100 % Application Rate	Yield dt/ha Variable costs €/ha TFI	500 770 2.0	500 760 1.9	500 750 1.7
75 % Application Rate	Yield dt/ha Variable costs €/ha TFI	485 745 1.5	495 740 1.4	500 730 1.3
50 % Application Rate	Yield dt/ha Variable costs €/ha TFI	470 700 1.0	490 695 0.9	500 690 0.8

Silage Maize, No-till Cultivation

Weather conditions Probability of occurrence		Unfavorable 20 %	Normal 60 %	Favorable 20 %
100 % Application Rate	Yield dt/ha	475	475	475
	Variable costs €/ha	800	785	780
	TFI	2.7	2.6	2.5
75 % Application Rate	Yield dt/ha	420	470	475
	Variable costs €/ha	760	750	740
	TFI	2.1	2.0	1.8
50 % Application Rate	Yield dt/ha	365	450	475
	Variable costs €/ha	710	700	695
	TFI	1.4	1.3	1.2

Prices

The market prices for winter wheat and silage maize fluctuate. Prices rise or fall with a respective probability of 50 % in each game period. The table below shows the possible price developments of winter wheat and silage maize. For example, the market price of winter wheat is 16.00 €/dt at the beginning of the game (period 0) and rises or falls by 1.00 €/dt in each period. The market price of silage maize fresh from the field is 2.50 €/dt at the beginning of the game and is subject to fluctuations of 0.20 €/dt in each period.

Field crop	Period 0	Period 1	Period 2
Winter wheat	16.00 €/dt	17.00 €/dt (50 %)	18.00 €/dt (50 %)
			16.00 €/dt (50 %)
		15.00 €/dt (50 %)	16.00 €/dt (50 %)
			14.00 €/dt (50 %)
Silage Maize	2.50 €/dt	2.70 €/dt (50 %)	2.90 €/dt (50 %)
			2.50 €/dt (50 %)
		2.30 €/dt (50 %)	2.50 €/dt (50 %)
			2.10 €/dt (50 %)

Political framework conditions

In each period, you receive an acreage premium of 300 € per hectare to cover fixed costs, meaning 200 ha x 300 € = 60,000 €/year. You receive the premium independently of your production decisions. At the beginning of the business management game, your cultivation decisions and application of plant protection products are subject to the codes of good agricultural practice. Nevertheless, you need to keep in mind that the framework conditions may change during the game!

Completing a game period

After completion of each game period, you are automatically provided with an overview of your cultivation decisions with regard to tillage, plant protection strategy, and treatment frequency index for each area. You will also receive information on pest and disease pressure levels and price developments as well as profit generated.

Premia and Prize Money in the Business Management Game

As a “thank you” for your participation, you will receive 10 € upon completion of the game. In addition, there are two other opportunities to win prize money.

1. Three randomly selected participants can win up to 300 € more, according to their decisions made during the business management game. Selected participants will receive 10 € for every 10,000 € profit earned during the game.
2. Three randomly selected participants will receive up to 300 € to donate to a non-profit organization of their choice (e.g. sports club, fire department, educational institutions, environmental protection organizations). The amount of the donation depends on the applied amount of plant protection products. The participant, who on average has the lowest Treatment Frequency Index level over all of the game periods, will receive 100 € to donate. The two other winners will receive a corresponding share of 100 € each, dependent on their respective Treatment Indices.

You may be confronted with unfavourable environmental and price developments during the game. However, in any case it is possible to win the highest prize money or donation amount.

Too Much Information at Once?

We would now like to test your knowledge of the game rules with a few questions. Afterwards, you can check your knowledge in a trial round! Subsequently, the first of 10 game periods will start. Moreover, you can always get back to the instructions of the business management game by clicking on the button “instructions” in the upper left-hand corner.

Please be aware that once the game has begun, decisions you make in each period cannot be taken back. The “back” button of your internet browser is unavailable during the game as this leads to ejection from the game thus cancelling entitlement to compensation for participation and any chance to win further prize money. We would also like to inform you that all assumptions and functional relationships used in the game are not claimed to be valid in reality. Nevertheless, we have made an effort to create a realistic design for the business management game.

---- Here, the business simulation game starts ----

At the beginning of every production period, the participants in the experiment could review their previous decisions including the chosen crop plan, tillage and pesticide strategy (TFI) as well as the development of prices and environmental conditions in the last production periods. Besides, they received statements of their bank account. The following screenshots *(see Figure A1-3) visualize examples of the decision matrix for winter wheat with conventional ploughing in the control group, pesticide and green nudge treatment (in German).*

Control group

Political framework conditions for the following game periods:

You receive an area payment of 300 €/ha from the state.

Your cultivation decisions and application of plant protection products are subject to the codes of good agricultural practice.

Figure A1. Decision matrix for winter wheat with conventional ploughing in the control group

Winterweizen mit wendender Bodenbearbeitung

Preisentwicklung					
Aktueller Produktpreis (Periode 5)		Unsicherer Produktpreis in der nächsten Periode (Periode 6)			
17,00 €/dt		16,00 €/dt (mit 50% Wahrscheinlichkeit)			18,00 €/dt (mit 50% Wahrscheinlichkeit)
Erträge und variable Kosten					
Umweltbedingungen und ihre Eintrittswahrscheinlichkeiten		Ungünstig 20 %	Normal 60%	Günstig 20 %	Ihre Entscheidung: Ich bewirtschafte
Ortsüblicher Pflanzenschutz (PSM 100%)	Ertrag dt/ha	90	90	90	ha Winterweizen PSM 100%
	Variable Kosten €/ha	1030	1000	970	
	Behandlungsindex	6,1	5,5	5,0	
Gezielte Reduzierung Pflanzenschutz (PSM 75%)	Ertrag dt/ha	85	87	89	ha Winterweizen PSM 75%
	Variable Kosten €/ha	960	940	920	
	Behandlungsindex	4,5	4,1	3,8	
Pauschale Reduzierung Planzenschutz (PSM 50%)	Ertrag dt/ha	72	78	86	ha Winterweizen PSM 50%
	Variable Kosten €/ha	890	880	870	
	Behandlungsindex	3,0	2,8	2,5	
					Max. Anbauumfang:140 ha

Pesticide tax

Political framework conditions for the following game period:

You receive an area payment of 300 €/ha from the state.

Your cultivation decisions and application of plant protection products are subject to the codes of good agricultural practice.

The state would like to further reduce the risks associated with the application of plant protection products. Thus, starting this game period there is an additional tax applied to the use of plant protection products. As a result, the costs associated with plant protection increase. The tax amount is dependent on your choice of application intensity and amounts to 25 € per unit on the Treatment Frequency Index. For example, a Treatment Frequency Index of 5.0 (corresponding to 100 % intensity and low pest and disease pressure on wheat) results in additional costs amounting to 125 € per hectare.

Figure A2. Decision matrix pesticide tax (from period 6 onwards)

Winterweizen mit wendender Bodenbearbeitung

Preisentwicklung					
Aktueller Produktpreis (Periode 5)		Unsicherer Produktpreis in der nächsten Periode (Periode 6)			
17,00 €/dt		16,00 €/dt (mit 50% Wahrscheinlichkeit)			18,00 €/dt (mit 50% Wahrscheinlichkeit)
Erträge und variable Kosten					
Umweltbedingungen und ihre Eintrittswahrscheinlichkeiten		Ungünstig 20 %	Normal 60%	Günstig 20 %	Ihre Entscheidung: Ich bewirtschafte
Ortsüblicher Pflanzenschutz (PSM 100%)	Ertrag dt/ha	90	90	90	ha Winterweizen PSM 100%
	Variable Kosten €/ha	1181	1138	1095	
	Behandlungsindex	6,1	5,5	5,0	
Gezielte Reduzierung Pflanzenschutz (PSM 75%)	Ertrag dt/ha	85	87	89	ha Winterweizen PSM 75%
	Variable Kosten €/ha	1073	1043	1014	
	Behandlungsindex	4,5	4,1	3,8	
Pauschale Reduzierung Planzenschutz (PSM 50%)	Ertrag dt/ha	72	78	86	ha Winterweizen PSM 50%
	Variable Kosten €/ha	966	949	933	
	Behandlungsindex	3,0	2,8	2,5	
					Max. Anbauumfang:140 ha

Green Nudge

Political framework conditions for the following game period:

You receive an area payment of 300 €/ha from the state.

Your cultivation decisions and application of plant protection products are subject to the codes of good agricultural practice.

The state would like to further reduce the risks associated with the application of plant protection products. From this point on, all plant protection products will be labelled with an additional warning sign, the so-called traffic light label. The label will be displayed as green, yellow or red depending on the product’s level of toxicity. For simplification reasons in the business management game, each plant protection intensity level will be given a traffic light colour.

Winterweizen mit wendender Bodenbearbeitung

Preisentwicklung					
Aktueller Produktpreis (Periode 5)		Unsicherer Produktpreis in der nächsten Periode (Periode 6)			
17,00 €/dt		16,00 €/dt (mit 50% Wahrscheinlichkeit)			18,00 €/dt (mit 50% Wahrscheinlichkeit)
Erträge und variable Kosten					
Umweltbedingungen und ihre Eintrittswahrscheinlichkeiten		Ungünstig 20 %	Normal 60%	Günstig 20 %	Ihre Entscheidung: Ich bewirtschafte
Ortsüblicher Pflanzenschutz (PSM 100%)	Ertrag dt/ha	90	90	90	ha Winterweizen PSM 100%
	Variable Kosten €/ha	1030	1000	970	
	Behandlungsindex	6,1	5,5	5,0	
Gezielte Reduzierung Pflanzenschutz (PSM 75%)	Ertrag dt/ha	85	87	89	ha Winterweizen PSM 75%
	Variable Kosten €/ha	960	940	920	
	Behandlungsindex	4,5	4,1	3,8	
Pauschale Reduzierung Planzenschutz (PSM 50%)	Ertrag dt/ha	72	78	86	ha Winterweizen PSM 50%
	Variable Kosten €/ha	890	880	870	
	Behandlungsindex	3,0	2,8	2,5	
					Max. Anbauumfang:140 ha

Figure A3. Decision matrix green nudge (from period 6 onwards)

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Die Wurzeln der **Fakultät für Agrarwissenschaften** reichen in das 19. Jahrhundert zurück. Mit Ausgang des Wintersemesters 1951/52 wurde sie als siebente Fakultät an der Georgia-Augusta-Universität durch Ausgliederung bereits existierender landwirtschaftlicher Disziplinen aus der Mathematisch-Naturwissenschaftlichen Fakultät etabliert.

1969/70 wurde durch Zusammenschluss mehrerer bis dahin selbständiger Institute das **Institut für Agrarökonomie** gegründet. Im Jahr 2006 wurden das Institut für Agrarökonomie und das Institut für Rurale Entwicklung zum heutigen **Department für Agrarökonomie und Rurale Entwicklung** zusammengeführt.

Das Department für Agrarökonomie und Rurale Entwicklung besteht aus insgesamt neun Lehrstühlen zu den folgenden Themenschwerpunkten:

- Agrarpolitik
- Betriebswirtschaftslehre des Agribusiness
- Internationale Agrarökonomie
- Landwirtschaftliche Betriebslehre
- Landwirtschaftliche Marktlehre
- Marketing für Lebensmittel und Agrarprodukte
- Soziologie Ländlicher Räume
- Umwelt- und Ressourcenökonomik
- Welternährung und rurale Entwicklung

In der Lehre ist das Department für Agrarökonomie und Rurale Entwicklung führend für die Studienrichtung Wirtschafts- und Sozialwissenschaften des Landbaus sowie maßgeblich eingebunden in die Studienrichtungen Agribusiness und Ressourcenmanagement. Das Forschungsspektrum des Departments ist breit gefächert. Schwerpunkte liegen sowohl in der Grundlagenforschung als auch in angewandten Forschungsbereichen. Das Department bildet heute eine schlagkräftige Einheit mit international beachteten Forschungsleistungen.

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