

Article

# Conflicts of Interests When Connecting Agricultural Advisory Services with Agri-Input Businesses

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**Abstract:** Conflicts of interests have been hypothesized when agricultural advisory services are connected to agri-input businesses. However, these have not been examined using large sets of advisory service and grower data. We provide quantitative insights into dependencies between service, crop production, sustainability and the level of agri-input business-linkage of extension workers. We analyzed 34,000+ prescription forms (recommendations) issued to growers in China, as well as grower interview data. Results revealed some conflicts of interest, but to a small extent and not always as expected. Both forms of advisory service (with and without business-linkages) heavily emphasize chemical pest management. However, grower interviews revealed that business-linked advisors recommend pesticides even 18% more often than non-business-linked advisors do (96% vs. 78% of advice). This advice was also often implemented (94% and 90% uptake). There is a slightly higher chance that dangerous pesticides are being recommended by business-linked advisors (0.4% vs. 0.14%), but these advisors recommended antibiotics less frequently (1.6% vs. 2.5%). No effects of the source of advice on yields or grower profits were found. Thus, there is no apparent economic disadvantage of growers taking advice from business-linked advisors. However, if pesticide use is a concern for human health and the environment, then the increased use of such products may further exacerbate existing problems. Depending on national priorities, countries may re-consider moving away from governmental extension services, and more closely analyze the advantages of promoting agri-business-linked advisory services (no public funds, better outreach) versus the disadvantages (slightly higher pesticide risks).

**Keywords:** crop production; plant protection; consumer risks; environmental risks; agricultural policy; food safety; public and private agricultural extension service; Plantwise

## 1. Introduction

Growers around the world need agricultural advice to successfully grow their crops, and consumers demand safe and healthy food. Societies wish to conserve the environment. Therefore, agricultural extension services exist to advise growers. Approaches to deliver such services vary across countries [1–5]. Many countries rely on the government, public extension services, some rely on private extension services, while many on a mix of them [6,7]. Limited or non-functional advisory services may lead to inappropriate agricultural practices and therefore to non-optimal food production or human and environmental risks. Despite such risks, the role of government agricultural services has

been reduced for financial reasons or due to overload with administrative and authority duties [2,3]. This means extension services may be overtaken by other service providers, sometimes run as small businesses, sometimes organized in advisory service associations [3]. Alternatively, lead growers or specialists in grower groups, cooperatives or agricultural enterprises advise their colleagues or employees [8]. In addition, larger agricultural input suppliers establish their own agricultural extension service networks, particularly in the Americas and Europe [9]. Finally, agricultural extension is, in most countries, also done by agri-input dealers when growers visit their shops [3,5]. Therefore, in some countries, the non-public sector is a key player in agricultural extension [2,7]. This raises a number of concerns, stated in FAO [10] as a conflict of interest when extension services that provide pest management advice are also involved in the sale of pesticides, particularly when extension staff need to supplement their income by sale of inputs, or when a lack of public extension services has resulted in pesticide retailers taking the role of advisors. In many countries, such conflict of interest is claimed a major cause of pesticide overuse, but studies have failed to prove such a hypothesis.

A number of food scandals attributed to pesticide misuse occurred in recent years [8,11]. Krautter and Niemann [11] reported that over 60% of sold pepper, grapes and strawberries are often contaminated with pesticide residues in Germany, and maximum residue levels exceed in over 20% of cases. In the early 2000s, greenhouse vegetable producers in Spain have been criticized for their overuse of pesticides [12], something that has been largely overcome through a shift towards bee-releases for pollination and a subsequent need for biological-based pest control. Also, in China, food scandals have been reported, such as Isocarbaphos-contaminated cowpeas [13] or Aldicarb- contaminated ginger [14]. As a result, consumers, retailers, certification bodies, and governments became sensitive in the area of food safety [15].

However, for the above-addressed concerns, it remains uncertain to what extent human or environmental hazards caused by pesticides are a result of or a lack of advice by agricultural extension services as opposed to other factors. Such factors could be independent decisions made by growers or a lack of safer, affordable alternatives, or of problems in the food chain. A recent study Zhang et al. [7] analyzed prescription forms issued by extension workers to growers on plant health problem diagnoses and management to answer the question whether linkage to agri-input businesses can affect such advice. Such analyses were possible because the global Plantwise program can if agreed by stakeholders, gather data on the interaction between growers and advisors, which can be used to assess the quality of advice [16]. Briefly, the Plantwise program uses plant clinics as a demand-driven service run by frontline extension workers with the aim to reach more growers than traditional office-based or field visit-based extension methods [17] or Farmer Field Schools [18,19]. Plant clinic sessions are held regularly at public places convenient to both growers and local extension workers, e.g., grower markets, retailer points, or central places of farmer cooperatives/associations/clubs [20]. The extension workers have agricultural education but have been additionally trained as plant doctors. Plant doctors provide on-the-spot diagnosis and advice for growers who bring plant health queries to the clinics [18]. This diagnosis and advice are provided to the grower in form of a written paper or electronic prescription, as known from the human health system (prescription by doctor for client to go to the pharmacy). The prescription helps the grower to better manage his/her crop and to potentially buy the right agri-inputs in a shop. At the same time data collected in the prescription form for each query may be held in a database [16]. Expert teams implement a formal assessment of the quality of diagnoses and advice [21]. Then, data can be used to inform decision making by plant health stakeholders, such as for pest surveillance, identifying training needs, or, as here presented, for analyzing quality of advice in the dependence of type of extension workers.

The Plantwise approach aims to integrate the plant clinic concept into the standard operations of existing extension providers, such as public or private organizations depending on the country. China is a good example where these different types of extension services, thus plant clinics co-exist. Plantwise has been implemented in China since 2012 [22]. By the end of 2016, there were 54 plant clinics being run by nearly a hundred trained plant doctors in Beijing, Guangxi and Sichuan province.

More than 40,000 prescription forms have been issued, thus advice given to growers. There are plant doctors with a number of different levels of agri-business connection: from no connection as a government or cooperative employed extension worker, to government-employed workers running their plant clinic next to an agri-input shop, to technicians with extension tasks in cooperatives without or with own agri-input business, to an entirely private agri-business approach of extension by agri-input dealers or supplier chains. In contrast, private business-driven advisory services, not linked to agri-input sales, but based on grower payments for services, are less common in China but currently developing. The diversity of plant clinic types, as well as the serious concern over pesticide contamination of food in China, makes it an optimal case for testing the above-mentioned reservations about the involvement of private sector, especially agri-input business in agricultural extension. As stated above, Zhang et al. [7] had already analyzed some data from prescription forms in China in 2014 and 2015 with regard to relevance of agri-business linkage for the quality of advice. Diagnosis and pest management recommendations appeared of high quality across all plant clinic types [7]. Business-linked plant doctors advised only slightly more highly hazardous pesticides than non-business doctors, but differences appeared small. It was also shown that agri-business-linked and non-business plant doctors are both able to reach many growers. Therefore, the authors concluded that differences between agricultural advisory services with different levels of agri-business-linkage are of little relevance, and are, therefore, unlikely a major reason behind human and environmental hazards in crop production. However, the study “only” considered the written advice from the extension worker to the grower and covered only two years of data. There was also no information on the amount and type of advice actually taken up by the grower.

We, therefore, conducted a small questionnaire-based grower survey in the plant clinic areas in Beijing municipality in China to understand how advice from plant doctors with different levels of linkage to agri-input sales is perceived by the grower and potentially implemented. Those plant clinics mainly serve small and medium-size commercial growers with focus on cash crops such as berries and vegetables for urban markets, here Beijing. We compared the questionnaire- data with a new analysis of an enlarged data set of written prescriptions covering three years. We hypothesized to find evidence that agri-input business linkages of agricultural extension may lead to (a) changes in advice quality, (b) an overuse of pesticides due to their more frequent recommendation and sale and therefore to potentially higher risks to humans, animals and the environment, or (c) an increase in profits by such extension workers to the disadvantage of growers. Results were aimed to serve as a case study for other Chinese provinces when analyzing potential adjustments of their agricultural extension systems [23]. In a broader sense, results will help to understand the advantages and disadvantages of countries’ different approaches in providing agricultural extension services to growers, and lessons learned may help to suggest further steps in improving plant health systems across the globe.

## 2. Materials and Methods

### 2.1. Agri-Extension Service Types

Agricultural extension workers trained as plant doctors provide free diagnosis and pest management advice to growers. Plant doctors in China consist of different types that sit along a continuum from a purely public to a purely private sector. They were divided into two broad groups (Table 1).

(1) Non-agri-business-linked plant doctors consist of government or farmer cooperative—employed extension workers with no business linkages. The government plant doctors are employees either under county/district level Plant Protection Stations or under township level Agri-service Centres and have their plant clinics in an area where growers are found, with few of them being mobile and few of them being placed inside or next to farmer cooperatives. Non-business cooperatives’ plant doctors are employed technicians of the cooperatives with extension tasks.

(2) The plant doctors with agri-business linkages consist of private plant doctors and government or cooperatives’ plant doctors with different types of agri-business linkage. Government plant doctors

with business linkage run their plant clinics in or next to an agri-input dealer or agri-service shop and may sometimes have family relationships with the shop owner. Cooperatives' plant doctors with business linkage are employees of the farmer cooperatives that run their plant clinic out of a cooperative-owned agri-input shop. Private plant doctors are owners of or sellers in an agri-input shop (or distributor, or service provider). The approach where private extension service providers, not linked to agri-input sales but paid for the service by the growers, is less common in China and not covered here.

**Table 1.** Sample sizes of agricultural extension workers (here plant doctors) with or without linkage to agri-input businesses in Beijing municipality in China. Their prescription forms on plant health problem diagnosis and pest management advice issued to growers (=queries) from 9 districts: Daxing, Miyun, Pinggu, Tongzhou, Changping, Huairou, Shunyi, Yanqing, Fangshan district, as well as the study population of interviewed growers consulting a subset of plant doctors in 5 districts: Yanqing (66 growers), Changping (6), Shunyi (80), Pinggu (64), and Fangshan (47).

Main Types of Agricultural Extension Workers	Agri-Extension Worker Survey 2014/2015/2016 <sup>1</sup>			Grower Survey 2016		
	# Plant Clinics	# Plant Doctors	# Queries Analysed	# Growers Interviewed	# Plant Clinics Covered	# Plant Doctors Covered
Without agri-input business linkage	14/11/13	19/23/28	2784/4643/5562	103	8	9
With agri-input business linkage	11/13/15	19/25/27	5368/7633/7838	160	6	7
Total	25/24/28	38/46/54	8152/12276/13400	263	14	16

<sup>1</sup> Only plant doctors and plant clinics considered, that had issued at least 10 prescription forms per year and/or run at least 5 plant clinic sessions per year.

## 2.2. Agri-Extension Worker Survey

To find data-based evidence on differences or similarities in the services provided by agricultural extension workers with different levels of agri-business linkage, the written advice given to growers in the Beijing municipality of China was analyzed between 2014 and 2016 (Table 1). This is a more in-depth analysis than the survey by Zhang et al. [7].

Prescription form analyses were conducted among all the 54 agricultural extension workers (=study population) that had been trained as plant doctors and are running 28 plant clinics in 9 agriculture driven suburban districts of Beijing municipality (Table 1). This study population should reflect about 2050 agricultural extension workers around Beijing (target population).

The analyses followed an unaligned, clustered sample design with the clinic districts as clusters of plant clinics. Plant clinics had been systematically established around Beijing step-by-step since 2012 [22]. Only the 2014, 2015, and 2016 data were analyzed assuring sufficient coverage and comparably large sample sizes enough to mine for potentially problematic pesticides. Over 500 plant clinic sessions have been held in this period (Table 1).

Prescription forms were analyzed that plant doctors provide on a plant health problem to a grower (form example [7]). Growers bring crop samples suffering from a plant health problem to the clinic, wherein a plant doctor diagnoses the problem and provides advice on how to manage it, usually following an integrated pest management approach [24]. Diagnosis and advice are captured on prescription forms, one per plant health problem. Forms contain information about the plant clinic location as well as the advising plant doctor, the advised grower, plant health problem symptoms and diagnosis as well as details on pest management [18]. The original copy of the form is given in written or electronically to the grower so that he/she can double-check the diagnosis in his/her field, monitor the problem, and can then decide whether and how to implement the recommended measures, including potentially visiting an agri-input shop with the prescription form. A copy of the form is kept

at the plant clinic and all information entered into a database. All 54 here-considered plant doctors issued at least 10 prescription forms per year and/or held at least 5 clinic sessions per year (less active or resigned plant doctors not considered). In total, 33,828 prescription forms had been issued to growers, and subsequently recorded, harmonized, and validated (8152 in 2014, 12,276 in 2015, 13,400 in 2016, Table 1). For validation of diagnosis and advice see below.

### 2.3. Grower Survey

To find out differences or similarities in uptake and impact of advice provided by agricultural extension workers with different levels of agri-business linkage, a grower survey was conducted in the Beijing municipality in 2016. Grower perception analyses helped to weight findings from the prescription form analyses (written advice) described above.

Structured interviews were implemented in five of nine plant clinic holding districts in Beijing municipality assuring acceptable coverage (Table 1). In total 263 growers, representing farm households, were successfully interviewed (=study population 263 plus five invalid interviews). They reflect a catchment area of approximate 8000 growers attending clinics around Beijing (target population as per prescription form data, Table 1). The here-interviewed growers were as much as possible systematically chosen and are linked to 16 plant doctors representing the 54 active plant doctors in Beijing area (Table 1). The survey was implemented between 7 and 11 November 2016 by two lead investigators and 10 enumerators supported by two staffs from the Beijing Plant Protections Station (=local implementing organisation of all plant clinics in Beijing municipality).

The questionnaire contained 51 questions, including 28 questions with regard to experiences of the grower from the last plant clinic visit(s) including plant health problem diagnosis and pest management advice, 8 questions on agricultural production on the farm as well as on uptake and impact of advice, and 15 administrative questions of grower characterization. To ensure questions were asked in a way allowing valid responses, a pilot survey on a small grower group was conducted and the interview structure and questions adapted. Then, individual growers were interviewed for about 30 to 40 minutes, and data entered the same day. Data quality was assured following procedures of Zhang et al. [7].

Interviewed growers were  $53 \pm 8$  SD years old (max 72, min 24) and 56% were males. Most had consulted a plant clinic  $2 \pm 1.6$  months prior to the interview (min 1, max 8 months, to a business-linked plant doctor  $1.9 \pm 1.4$  months, to a non-business doctor  $2.7 \pm 1.9$  months ago). Next to the main grower,  $2.3 \pm 28$  farmworkers worked on a farm (min 0, max 35,  $50 \pm 27\%$  males). Most interviewed growers had small or medium-sized commercial farms largely focusing on cash crop production and many under greenhouses. The farm income (not profit) from all of his/her crops was  $18,834 \pm 77,226$  USD ( $129,887 \pm 53,2591$  CNY) per season 2015 to 2016 (min 0, max 870,000 USD or 6,000,000 CNY). The main crop of a farm in terms of area and income was usually grown on  $0.25 \pm 0.41$  hectares ( $3.7 \pm 6.1$  mu) approximately indicating farm size. The problem crop consulted on, was grown on  $0.17 \pm 0.20$  hectare ( $2.5 \pm 3$  mu). The farm income from the consulted problem crop, usually a cash crop, was  $8986 \pm 56,297$  USD ( $61,975 \pm 388,252$  CNY) per season (min 0, max 828,240 USD or 5,712,000 CNY).

### 2.4. Assessing Outreach of Agricultural Extension Services

We analyzed the number of prescription forms (written recommendations) issued to growers per plant doctor per clinic session, the number of sessions per year reflecting regularity, the number of different growers per plant doctor reflecting primary reach, as well as the consulted crops and plant health problems.

Grower interviews revealed repeat visits reflecting regularity, follow-up services, and also the consulted crops and plant health problems.

### 2.5. Assessing Quality of Diagnosis of Plant Health Problems

The diagnosis as on the prescription forms was first validated for correctness by a team of national and local plant protection experts and senior agricultural extension officers as per Danielsen et al. [21]. Briefly, experts compared the written diagnosis with (a) the described symptoms (descriptive part of the prescription form), (b) with the chosen symptom tick boxes (24 symptoms possible), and (c) with the causation group tick boxes (see [7]). A diagnosis was accepted as correct if (a), (b), and (c) were fitting together and were plausible (i.e., problem known from the region and considered crop), as well as when all key symptoms were mentioned. In other Plantwise countries, also specificity and distinctiveness of symptoms are accessed during validation [16], but this was not considered here. To assess the number of details, words were counted in the descriptive diagnosis part of each form.

Moreover, growers' view was assessed through questions on diagnosis correctness (=validity) and comprehensiveness (=details and accuracy).

### 2.6. Assessing Quality of Advice for Plant Health Problem Management

The written advice given on the prescription forms was validated and agreed on by an expert team as described above. First efficacy, safety, the practicability of the written descriptive advice on the prescription forms were judged in relation to the made diagnosis of the plant health problem (see for safety details below).

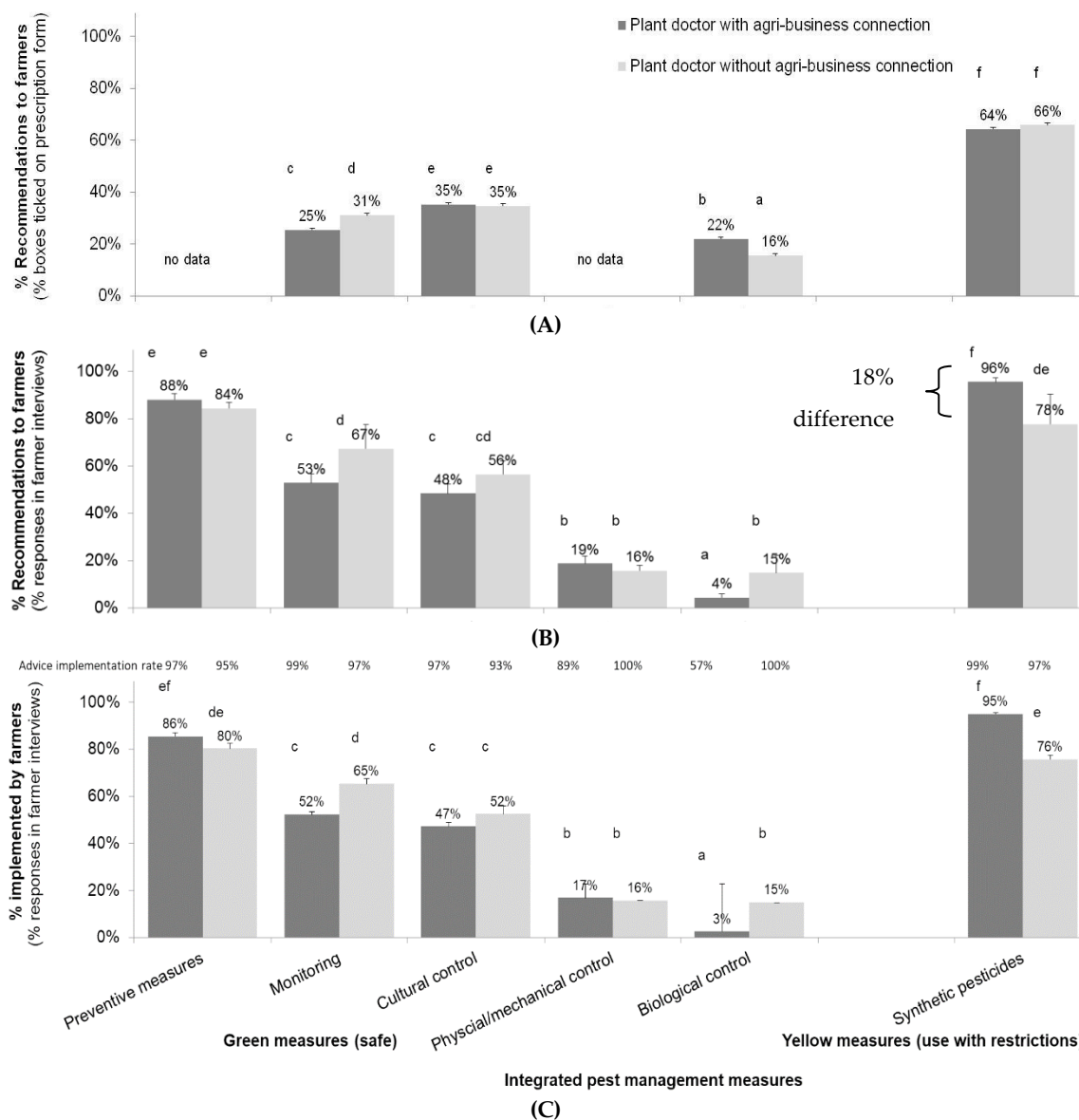
Then the quality of advice was additionally characterized through validating comprehensiveness of advice to growers. Comprehensiveness was judged according to what extent most or all integrated pest management (IPM) approaches had been advised on, this is, whether direct as well as preventive management measures were advised on, whether pest monitoring and decision information was provided, and whether non-chemical as well as least toxic chemical options with restriction details for use were provided. Finally, words were counted in the descriptive advice part of the form as a parameter for detail.

Moreover, growers' views were assessed through advice validity and comprehensiveness with regard to IPM measures, as well as aspects of economics, practicability, and effectiveness. Moreover, advice details such as application types, dosages, pre-harvest intervals, and personal protective clothing were assessed.

### 2.7. Assessing Uptake and Impact of Advice

Growers were asked what proportion of the provided advice they had have fully, partly or not implemented. This information was assessed per each of the main IPM measurers [24], this is, preventive measures, pest monitoring and decision making, cultural control, physical/mechanical control, biological control (macrobiotics, microbiotics, safe botanicals, biofertilizers with pesticidal effects and antibiotics), and the use of synthetic pesticides. This allowed also comparisons to the written advice given on these measures on the prescription forms (Figure 1A,B).

As written pest management advice on the prescription forms does not give insights on the level of implementation by the grower, growers were asked how implemented advice helped in managing the plant health problem, as well as how much of the potential yield loss was prevented. Moreover, income from selling the harvest, input costs including the costs of the advice implementation were assessed and profit calculated.



**Figure 1.** Plant protection recommendations given to growers by agricultural extension workers (A,B) and implemented by growers (C) depending on the agri-input business linkage of extension workers (here plant doctors) in plant clinics in Beijing municipality, China between 2014 and 2016 (A) and 2016 (B,C). A = prescription form tick-box data, B and C grower interview data. C shows the rate of implementation of advice of B according to grower statement. Dark grey bars = agri-business-linked, light grey bars = without agri-business linkage, biological control includes macrobials, microbials, safe botanicals, biofertilizers with pesticidal effects and antibiotics, (error bars = SEM, different letters on bars indicate differences according fdr -corrected comparisons using chi-square likelihood ratios at  $p < 0.05$  based on per-plant doctor & clinic session - nested data).

### 2.8. Assessing Risks Through Pesticides

First, the written advice on the prescription forms was analyzed for the number of pesticides advised by the different plant doctor types. Moreover, proportions of non-IPM compatible measures, particularly problematic pesticides, were analyzed. Briefly, problematic pesticides are red list pesticides [25,26] including (a) highly hazardous active ingredients, this is toxicity classified as 1a, 1b according to the World Health Organisation [27], (b) banned as organic persistent pollutant according to the Stockholm Convention [28], banned as ozone layer destructive chemical according to the Montreal Protocol [29], and banned according to the prior informed consent in the Rotterdam convention [30]. Finally, the considered

agents must be nationally registered for the considered crop [31]. In other words, valid advice must follow the Plantwise Pesticide Policy and the Plantwise red list of plant protection agents [25,26]. Special cases are antibiotics that are usually rarely used in plant protection, and particularly not in IPM programs due to possible microbial resistance development and human health risks. In China, however, antibiotics are regarded as one type of biopesticides that are allowed and encouraged in “the Green Control” program of China [32,33]. In the here-presented paper, non-IPM compatible measures consist of above-mentioned red list measures as well as antibiotics.

The growers were interviewed for their level of trust in the advice from different plant doctor types and the reason behind trust or distrust. Moreover, growers were asked for their opinion on conflicts of interest of extension workers selling agri-inputs next to their advice work.

### 2.9. Data Analyses

The owner of the local data sets is the extension service implementing organization, here the Beijing Plant Protection Station. Personal information of plant doctors and growers as well as plant clinics’ precise geographic location have been deleted prior analyses.

Prescription form data were only used from plant doctors and plant clinics, which had been active, this is, has issued at least 10 prescription forms to growers each year or having held at least 5 plant clinic sessions each year. Most data of form’s variables were averaged per plant doctor and its clinic as well as per clinic session date due to large differences in sample sizes for each of them. Although this reduces analyzable sample size, it provides person- and day-independent data (=plant doctor- and session-nested data). All grower interview raw data from answers to qualitative and quantitative questions were analyzed without averaging as interviews were conducted at a one-time step.

Scale data, regardless of being from prescription forms or grower interviews, were analyzed for normal distribution using histograms, Q-Q plots and the one-sample Kolmogorov Smirnov test [34]. The influence of the independent explanatory factor “plant doctor main types” as well as factor “year” were tested on each of the dependent variables: outreach, diagnosis, pest management advice including pesticide risks, as well as uptake by growers and impact described above. General linear models GLM were applied in case of a normal distributed scale data, lack of many extreme data, and independence of variables. An independent sample t-test was applied for comparisons between agri-business-linked and non-business plant doctors. Multiple comparison tests, such as for comparing different IPM measures, were implemented using Tukey test in cases of equal variances, or Games Howell test in case of unequal variances [34]. In case of nominal or ordinal data, chi-square tests and likelihood ratios were used. Multiple comparison tests are not available for such data and therefore *p*-values obtained from chi-square likelihood ratios were false discovery rate (fdr)-corrected.

## 3. Results

### 3.1. Outreach of Agricultural Extension Services

Our hypothesis that both extension worker types similarly reach growers (as suggested in [7]) was partly rejected because business-linked extension workers appeared to have a slightly larger outreach than the non-business ones.

#### 3.1.1. Agri-extension worker’s written advice

A plant doctor, independent of its type, issued on average  $243 \pm 27$  SD prescription forms covering plant health problem diagnosis and pest management advice to growers during  $17 \pm 12$  plant clinic sessions per year.

Agri-business-linked plant doctors reached slightly more growers than did non-business plant doctors ( $292 \pm 12$  vs.  $182 \pm 31$  forms per year,  $t_{(1, 54)} = -1.9$ ,  $p = 0.01$ ,  $19 \pm 7$  vs.  $13 \pm 4$  forms per session). Both plant doctor types held comparable numbers of advisory sessions every year ( $17 \pm 12$  and  $15 \pm 31$ ,  $t_{(1, 46)} = 0.3$ ,  $p = 0.7$ ). Each agri-business-linked plant doctor served  $94 \pm 10$  different growers per year,



and each non-business plant doctor  $66 \pm 16$  growers (=primary reach). This totaled 4557 different growers by all business-linked plant doctors in the Beijing area over three years vs. 3707 growers by non-business doctors.

### 3.1.2. Growers' View

Most growers visited the plant doctors, regardless of their type, about once a month, i.e.,  $13 \pm 12$  times per year (max 60 times,  $n = 244$ ). However, growers visited agri-business-linked plant doctors about twice as often as the growers visiting non-business plant doctors ( $t_{(1, 242)} = -6, p < 0.0001$ ), confirming the prescription form conclusions on outreach. Therefore, the rate of growers visiting a plant doctor only once was higher for non-business-linked plant doctors (15%) than for visits of agri-business-linked doctors (1%). This is, although 99% of the growers expressed the intention to visit the plant doctor, regardless of its business linkage, again.

## 3.2. Quality of Diagnosis of Plant Health Problems

Our hypothesis that business-linked extension workers may diagnose plant health problems less correct than do non-business-linked extension workers was largely rejected. Analyses of prescription forms and grower interviews confirmed the ability of both extension worker types to conduct a high quality diagnosis of plant health problems from samples brought by the growers.

### 3.2.1. Agri-Extension Worker's Written Advice

Overall, plant health problems were usually correctly diagnosed, this is, over 99% of all written diagnoses made by plant doctors, regardless of their type, were accepted as "correct" according to validation by plant protection expert teams.

The diagnosis quality by agri-business-linked plant doctors was as correct and as detailed as by non-business plant doctors ( $99.6\% \pm 11\%$  vs.  $99.9\% \pm 2.6\%$  correct, plant doctor and year nested data  $t$ -test:  $t_{(1, 82)} = 9.6, p = 0.07, 19 \pm 15$  and  $22 \pm 8$  words symptom description,  $t_{(1, 109)} = -1.5, p = 0.26$ )

### 3.2.2. Growers' View

Growers judged the diagnosis by plant doctors (written + oral) as mostly correct ( $97\% \pm 16\%$ ). In contrast to written prescription information, growers judged agri-business-linked plant doctors providing slightly less detailed diagnosis than non-business plant doctors (54% vs. 80% as very precise, 45% vs. 16% fairly precise, 1.3% vs. 4% acceptable).

## 3.3. Quality of Advice on Plant Health Problem Management

Our hypothesis that business-linked extension workers may provide less IPM-compatible pest management and more pesticide advice than do non-business-linked extension workers was only partly confirmed. Both, written prescriptions as well as grower perceptions indicate that agri-business linkage seems generally not to negatively influence, with few exceptions, the generally high quality of pest management advice. A problem is that both extension worker types, with and without agri-business linkage put a major emphasis on chemical control, and business-linked workers even a bit more.

### 3.3.1. Agri-Extension Worker's Written Advice

Overall, written advice was of good quality, this is,  $96\% \pm 8$  SD % of all recommendations written on the prescription forms by plant doctors, regardless of their type, were accepted as "valid" according to a validation team of plant protection experts.

In detail, advice of agri-business-linked plant doctors was as valid as of non-business-linked plant doctors ( $95\% \pm 9\%$  and  $97\% \pm 6\%$ , plant doctor & year nested  $t_{(1, 82)} = 2.1, p = 0.45$ , GLM:  $F_{(1, 85)} = 0.3, p = 0.59$ ). Business-linked doctors provided as comprehensive advice as did non-business doctors ( $88\% \pm 24\%$  and  $94\% \pm 7\%$  comprehensiveness,  $t_{(1, 70)} = 8.5, p = 0.17$ ) and as detailed ( $72 \pm 55$  and

76 ± 42 words written advice,  $t_{(1, 109)} = 2.1, p = 0.57$ ). Plant doctors with and without agri-business linkage advised comparably frequent the different main types of IPM measures (Figure 1A). Particularly synthetic pesticides were similarly often advised by both plant doctor types (64% vs. 66%) as were cultural measures. However, plant doctors with agri-business linkage advised slightly more often biological plant protection measures, largely biopesticides and other natural source products (ca. 6% more) but less often pest monitoring (ca. 6% less) than did non-agri-business-linked plant doctors.

### 3.3.2. Growers' view

Overall, growers judged the advice of plant doctors, regardless of their type, as clear (97%) economic (95%), practical (96%) and effective (98%). There was no difference between plant doctor types.

The advice of agri-business-linked plant doctors was judged by growers as valid as of non-business plant doctors (91% ± 28% and 84% ± 37%, chi-square likelihood ratio = 3.1,  $df_{(1, 258)}, p = 0.077$ ). Compared to the written advice analyzed from the prescription forms, differences appeared when asking growers about the advice (written + oral) they got (and remembered) on different types of IPM measures. Often, growers seem to have received more advice than was shown on the prescription forms.

Interestingly, there was no difference between plant doctor types with regard to advising on synthetic pesticides when analyzing prescription form data (see written advice), but a difference when asking for growers' views (written + oral advice). Growers stated they had received approximately 18% more pesticide-advice from agri-business-linked plant doctors than from non-business-linked ones (96% vs. 78%) (Figure 1B). As for biological measures, grower interviews revealed that non-business plant doctors advised 11% more biological measures than did agri-business plant doctors, which is the opposite of findings from prescription form data. Non-business plant doctors advised pest monitoring 14% more often than did agri-business-linked plant doctors, something that was in the same trend from the prescription form data (corresponding tick-box on the form).

There were, in most cases, no differences between agri-business and non-business-linked plant doctors for advice details, such as on how to apply products (92% ± 27% and 92% ± 28% of cases), dosage details (97% ± 18% and 92% ± 28%), or pre-harvest intervals (90% ± 30% and 81% ± 39%). Agri-business-linked plant doctors provided more information on personal protective equipment (88% ± 33%) than did non-business doctors (68% ± 47% of cases).

### 3.4. Uptake and Impact of Advice

Our hypothesis that growers may trust and follow advice from non-business linked extension workers more than from the private sector was rejected. Similarly, our hypothesis that growers advised by non-business extension workers invest less money in plant protection measures than growers advised by agri-business-linked workers (who may try to sell their agri-inputs) was largely rejected.

#### Growers' view

Growers trusted the advice from plant doctors with agri-business linkage to the same extent as the advice from non-business plant doctors (>80%, chi-square likelihood ratio = 9,  $df\ 4$  trust categories, 191,  $p = 0.06$ ). Agri-business linkage did usually not influence the generally high uptake of advice by growers. About 94% of growers claimed to have fully implemented the advice from agri-business-linked plant doctors vs. 90% implementing the advice from non-business plant doctors (Figure 1C). Only 5.6% versus 8.4% of growers partly implemented the advice, respectively, and 0.6% vs. 2.1% did not follow the advice. Growers' implementation level of the different IPM measures advised on, did, overall, not depend on plant doctor type ( $t_{(255)} = 1.2, p = 0.21$ , Figure 1). This is with the exception of implementing biological measures, where growers advised by agri-business-linked plant doctors only implemented the advice in 57% of cases, whereas growers advised by non-business doctors nearly always applied the advice.

Yield values indicate that the interviewed growers were, despite being of small or medium size, professional commercial farmers. For example, the average yield of tomatoes was 73 ± 39 SD tons per

hectare (39 interviewed farmers), cucumber  $77 \pm 61$  ( $n = 31$ ), green bean  $28 \pm 17$  ( $n = 28$ ), pepper  $76 \pm 40$  ( $n = 18$ ), Chilli  $48 \pm 33$  (17), strawberry  $27 \pm 34$  (16), romaine lettuce  $32 \pm 16$  (15), and Chinese cabbage  $57 \pm 42$  tons (11). Overall, 85.3% and 85% of growers agreed that the advice from business-linked and non-business plant doctors did help to avoid yield loss, respectively. Roughly, growers saved  $51\% \pm 32\%$  of their crop when implementing the plant doctor advice, in other words, they avoided such anticipated yield loss.

Growers advised by agri-business-linked plant doctors saved the same amount of their crop through implementing advice as did growers advised by non-business plant doctors ( $53\% \pm 33\%$  and  $49\% \pm 31\%$  prevented yield loss, 24 of 49 tons saved and 28 of 54 tons per ha, respectively,  $t_{(162)} = 0.8$ ,  $p = 0.44$ ). Agri-business linkage of plant doctors had no major influence on the input costs for plant protection and not on the other input costs. Growers advised by agri-business-linked plant doctors did not make more profit than growers advised by non-business plant doctors ( $21,588 \pm 42,475$  and  $22,293 \pm 35,088$  USD per ha per season,  $t_{(176)} = 0.1$ ,  $p = 0.9$ ), indicating that both types of extension workers well-helped growers to grow their high-value crops (Table 2).

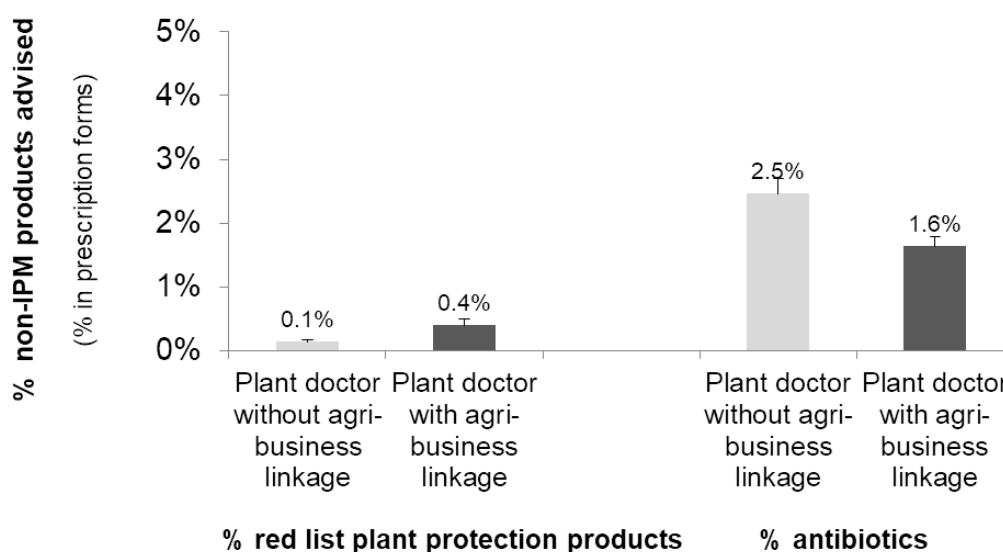
**Table 2.** Financial balance for cash crops advised on by agri-input-business-linked or non-business-linked agricultural extension workers (here plant doctors) in Beijing municipality in 2016, N represents each sample sizes of the 263 growers interviewed (differences according to independent samples t-test at  $p < 0.05$ ).

Types of Agricultural Extension Workers		% Yield Loss Avoided Following Advice	Financial Balance of Problem Cash Crops Advised on (USD/ha/season)		
			Cost of Growing Crop <sup>1</sup>	Income	Profit
Without agri-input business linkage	Mean	49	8585	31,206	22,293
	SD	31	12,085	40,639	35,088
	Max	100	78,300	290,000	217,500
	Min	0	0	0	-43,500
	N	77	83	76	75
With agri-input business linkage	Mean	53	8283	29,707	21,588
	SD	33	13,127	48,455	42,475
	Max	100	92,438	466,071	416,357
	Min	0	0	0	-30,813
	N	145	150	146	146
Difference	t	-0.8	0.2	0.2	0.1
	p	0.44	0.86	0.81	0.90
Average	Mean	51	8390	30,220	21,827
	SD	32	12,740	45,842	40,041
	Max	100	92,438	466,071	416,357
	Min	0	0	0	-43,500
	N	222	233	222	221

<sup>1</sup> total of crop production costs including fertilizers, plant protection measures and labor costs of employed farm workers but excluding family farm members. <sup>2</sup> cash crops such as strawberry, tomato, cucumber, Chinese cabbage, Romaine lettuce, eggplants, chili, celery, watermelon, green beans. N is sample size.

### 3.5. Risks Through Pesticides

Our hypothesis that a business-linkage of agricultural extension services may lead to more pesticide usage and therefore more risks was only partly proven. Both extension worker types heavily rely on pesticide advice (Figure 1), but red-list pesticides are rare (Figure 2)



**Figure 2.** Non-IPM compatible plant protection products recommended to growers by non-business and agri-input-business-linked agricultural extension workers (here plant doctors) in plant clinics in Beijing municipality of China between 2014 and 2016 (% red list products or % antibiotics as per issued prescriptions form  $\pm$  SEM). Red list products as per Stockholm Convention, Rotterdam Convention, Montreal Protocol, WHO toxicity class 1a, 1b, [25,26]. Dark grey bars = agri-input business-linked, Light grey bars = without agri-input business linkage, only active plant clinics are shown with more than 10 issued prescription forms per year (different letters on bars indicate differences according independent samples t-test with session and plant doctor nested data at  $p < 0.05$ ).

### 3.5.1. Agri-Extension Worker's Written Advice

Plant doctors with and without agri-business linkage seem to similarly often advise pesticides (84% vs. 86%) (Figure 1A). Business-linked plant doctors advised few but slightly more red-list products ( $0.4\% \pm 5.9\%$ ) than did non-business plant doctors ( $0.14 \pm 1.8\%$ ), but differences are tiny (Figure 2). ( $t_{(1, 6383)} = 16.7$ ,  $p = 0.038$ ). Business-linked plant doctors advised in 0.23% of cases Carbofuran and Dichlorvos (DDVP), in less than 0.1% of cases Cadusafos, Cyfluthrin (Beta Cyfluthrin), Methamidophos, Methomyl, Monocrotophos, Omethoate, Oxydemeton-methyl (Metilmerkaptophosoksid) and Parathion, and in less than 0.01% Difolatan (Captafol), Methidathion, Nicotine. In contrast, non-business plant doctors only advised in 0.12 % of cases Dichlorvos (DDVP), in less than 0.1% Carbofuran, Cyfluthrin (Beta Cyfluthrin), and Nicotine, and in less than 0.01% Bromadiolone.

Business plant doctors advised few, but slightly less antibiotics than did non-business-linked plant doctors ( $1.6\% \pm 9.1\%$  vs.  $2.5\% \pm 11\%$ ,  $t_{(1, 6383)} = 32.3$ ,  $p = 0.002$ ). Business-linked plant doctors advised in 1.2% of cases Streptomycin and in less than 1% Zhongshengmycin and other antibiotics. In contrast, non-business plant doctors advised in 0.2% of cases Streptomycin, and in less than 1% Zhongshengmycin.

### 3.5.2. Growers' View

Growers expressed to have received about 18% more pesticide-advice from agri-business-linked plant doctors than from non-business-linked ones (96% vs 78% in written and oral advice) (Figure 1B). There seems little to no evidence that growers see conflicts of interest in plant doctors selling agricultural inputs next or during their extension work. Only 7% of growers would dislike if non-business plant doctors start selling agri-inputs. Around 73% of growers would actually even expect non-business plant doctors to sell agricultural inputs (vs. 92% expecting this from agri-business-linked plant doctors),

As such, 92% of agri-business-linked plant doctors advised growers to actually buy their agricultural inputs, whereas only 52% of non-agri-business plant doctors advised the same, e.g., in a nearby shop. Consequently, 99% of growers bought advised products at or next to the plant clinic of a business-linked

plant doctor, whereas they never did so in case of a non-business-linked plant doctor. The reasons for a grower to buy agri-inputs at a plant doctor were trust (94%) or good experiences with previous use (53%), saving time (80%), a good price (62%), to try out new things (16%), or the plant doctor was the only source for a certain product (5%).

#### 4. Discussion

This study is a step forward in better understanding of potential risks when public agricultural extension services are outsourced to private bodies. We provide insights into advantages and disadvantages of including the private sector in agricultural extension (Table 3). We were able to show that there are some conflicts of interest, although they seem usually small and not to the disadvantage of the grower, but rather to the consumer and the environment. This confirms only partly the often-raised concerns when agri-input sellers become linked to extension services [2,9,10,35,36].

A major problem is that all here-studied types of agricultural extension workers heavily rely on recommending pesticides. Therefore, prescription form data, i.e., the written advice, did not reveal an over-prescription of pesticides due to the business-linkage of the extension worker in our study and not in the analyses of Zhang et al. [7]. In contrast, grower interview data, i.e., written plus oral advice, suggest generally more diverse and more comprehensive advice than written down. This is understandable as oral communication adds to advice. It may also be the case that more pesticides are verbally advised than in writing because many pesticides are effective against certain pests in minor crops but not registered for those. In any case, grower interviews indicated, despite a relatively small sample size, that business-linkage can indeed lead, to some extent to more advice of pesticides (this is about 18% more). Unfortunately, grower interviews also suggest that such advice is largely implemented leading to a generally high application of pesticides (85% of pest management queries, 97% when advised by business-linked extension workers vs. 76% by others). Therefore, although not on large level, it quantifies the potential higher risks for the consumers and the environment when public agricultural extension services are outsourced to private bodies. A more in-depth grower survey across several provinces and services across China may be needed to reveal more insights.

Otherwise, there is little evidence of other conflicts of interest as input costs of growers seemed comparable regardless of who gave the advice, as well as the profits (= output minus input). The good news is, that extension service quality, including diagnosis and pest management advice, was generally high, meaning technically correct and complete, and this regardless of the type of extension worker (Figure 1 and Table 3). Analyses of prescription forms and grower interviews both confirmed a high validity of diagnosis (>99%, and 97%, respectively), although growers judged the agri-business-linked extension workers providing fewer details than non-business linked-workers (54% vs. 80%). This seemed, however, not to have led to wrong advice. Pest management advice was judged valid in most cases according to expert teams that validated prescription forms, and according to grower interviews. In some countries such high acceptance rates by validation teams are also found, such as in Zambia (S. Toepfer, pers. observation, 2015), but in other countries, acceptance rates can be much lower, such as in Uganda [36,37].

**Table 3.** Advantages and disadvantages of agri-input-business linkage in agricultural extension services in Beijing municipality, China.

Agricultural Extension Service Quality	Effect of Agri- Input Business Linkage	Difference to Non-Business Linkage <sup>3</sup>	Source <sup>1</sup>	Agricultural Extension Service Quality	Effect of Agri-Input Business Linkage	Difference to Non-Business Linkage <sup>3</sup>	Source <sup>1</sup>
<b>Diagnosis quality</b>				<b>Uptake and impact</b>			
Correctness	↔		P, G	Grower trust advice	↔		G
Details of symptom description	↔		P	Advice implementation	↔		G
	↓	-26%	G	preventive, monitoring, cultural & physical control	↔		G
<b>Advice quality</b>				chemical control	↔		G
Validity	↔		P, G	biological control	↓	-43%	G
IPM comprehensiveness	↔		P, G	Advice helped to manage the problem	↔		G
Preventive measures	↔		G	Avoided yield loss	↔		G
Monitoring and decision making	↓	-5, -14%	P, G	Costs of crop production	↔		G
Cultural control	↔		P, G	Costs of advised fertilizers	↔		G
Physical control	↔		G	Costs of advised pest management	↔		G
Biological control <sup>2</sup>	↑	6%	P	Income from crop	↔		G
	↓	-11%	G	Profit	↔		G
Synthetic pesticides	↔		P	<b>Risks through pesticides</b>			
Details of recommendation	↔	18%	G	Advised red list products	↑	0.5%	P
	↑		P	Advised antibiotics	↓	-1%	P
Details on protective equipment	↑	24%	G	Grower expects agri-inputs are sold at the plant clinic	↑	21%	G
Details on pesticide use (application type, dosages, pre-harvest intervals)	↔		G	Grower dislikes agri-inputs are sold at the plant clinic	↓	-7%	G
<b>Outreach</b>				Advised to buy agri-inputs	↑	40%	G
Prescriptions to growers	↑	62%	P	Advised agri-inputs available at the plant clinic	↑	95%	G
Grower repeat visits	↑	47%	G	Grower bought advised agri-input at the plant clinic	↑	99%	G
				<b>Sustainability</b>			
				Need for public funds for advisory service	↓	not quantified	

<sup>1</sup> P = 34,000 writing prescription data from Beijing area between 2014 and 2016, G = 263 grower interview data from Beijing area in 2016 (cropping season 2015 to 2016). <sup>2</sup> note that plant doctors in China consider biocontrol comprising macrobials and microbials, antibiotics and natural source product, whereas in the grower interviews biocontrol comprised only microbial and microbial agents which agri-input shops may not have had available. <sup>3</sup> values are in percent points and are only shown if differences were significant at  $p < 0.05$ . The words in bold are group titles of the following items.

The large majority of extension workers, regardless of their affiliation with agri-businesses, appear to adhere to regulations [26,31,32] and IPM standards such as advising multiple pest management methods including monitoring and decision making [24] (Figure 1). A small exception is that growers advised by non-business-linked plant doctors were more advised on biological control products and also used more than the other growers (100% vs. 57% advice uptake rate, Figure 1B,C). This was likely a result of availability, meaning that some governmental plant clinics occasionally had biocontrol products for free distribution due to government subsidy programs for green measures implemented via the plant clinics [32,33,38] (Figure 1B). It confirms [35,39] suggesting that IPM-focused extension services can be an effective approach to implementing such policies by transferring high-quality and case-specific advice to growers. When biopesticides and natural source products are included under biological control, as in the prescription form data, then there is no difference anymore between plant doctor types. All together, non-chemical direct control measures are less often advised than preventive measures or chemical control regardless of the extension worker type but possible reasons remain hypothetical such as believed efficacy of control measures, availability, or costs.

As for chemical control, risks of advice with highly hazardous banned pesticides were low indicating a high knowledge of advisors and/or strong legislation. However, business-linked extension workers indeed advised slightly more red-list products (0.4%) than did non-business extension workers (0.14%), but differences are tiny (less than  $\frac{1}{2}$  percent points), and probably not relevant (Figure 2). It should be mentioned that most of the few highly hazardous pesticides showing up in plant doctors' written prescriptions are not yet banned in China [31,40], thus, they are legally allowed to be sold and used. Thus, those few extension workers, advising highly hazardous products are not doing anything illegal, but they definitely could have provided safer and more IPM-compatible advice. Additional training could likely solve this problem [41]. In contrast, business-linked extension workers advised few, but slightly fewer antibiotics than did non-business-linked extension workers (1.6% vs. 2.5%). As with highly toxic pesticides, antibiotic advice was rare (2%). Antibiotics in plant protection are a special case for China. Although antibiotics are considered IPM-incompatible in many countries or are even totally banned, in China, they are one of the permitted types of biopesticides and are even promoted for use according to Chinese agri-policies like the Green Control Policy [33]. Since antibiotics are considered safe to the user, they are used in vegetable production in China. A comparable situation is found in fruit protection in the USA [42]. This should, however, not downplay the concerns behind the use of antibiotics in plant protection [7,43], as this can potentially lead to an additional uptake of antibiotics by humans through plant produce, i.e., in addition to the uptake through meat (Jorgensen and Wernli 2016), and through medication of human bacterial diseases [44]. Increased exposure to antibiotics, in turn, raises the risk of potential resistance development of human pathogens. This is particularly crucial in plant protection as antibiotic residues on fruits and vegetables lead to a low dose scenario, which is particularly prone to resistance development [43]. Nevertheless, overall usage of antibiotics remains small, and the difference between extension worker types is less than 1% only. In summary, both, written prescriptions as well as grower perceptions indicate that agri-business linkage seems not to negatively influence, with few exceptions, the generally high quality of plant health problem management advice (see 95% and 97% validity, similar comprehensiveness with regard to IPM measures, Table 3).

The main hypothesis of the study was, whether there are conflicts of interests, as for example agri-business-linked plant doctors trying to sell more pesticides than needed, and growers spending more money on plant protection products. This was only partly confirmed. Business-driven extension workers indeed advised, as already stated, about 18% more pesticides than other extension workers, and growers seem to even implement that advice, thus buy the pesticides. However, growers seem to not spend more money on plant protection than other growers, which suggests that there is at least no oversell of expensive pesticides (Table 2). This is reflected in the data showing that extension worker type had no major influence on the input costs for plant protection and not on the other input costs. It also did not influence the income or profit of the growers indicating that both types of

extension workers generally well-helped growers to grow their crops (53% and 49% prevented yield loss of usually heavily disease-affected high-value vegetables and berries). Most growers (86%) see no problem when extension workers are also selling agricultural inputs. Growers even appreciate this approach due to convenience (80%) and price (62%). Interestingly, many growers are not sure what consumers would think when agricultural extension services get connected to agri-input sales (60%), but at least some growers see potential concerns by the consumers (16%). This is interesting, as the here-studied growers mainly produce strawberries, tomatoes, cucumbers, Chinese cabbage, Romaine lettuce, eggplants, chili, celery, watermelon, green beans and others vegetables and some fruits like peaches for the large urban Beijing market. This market is sensitive to pesticide-contaminated food [15,32].

Finally, after having revealed some of the problems when linking agricultural extension services to the private sectors, also advantages should be addressed (Table 3). As for the present study, there are two major advantages of considering the private sector. First, business approaches can more likely maintain a network of agricultural extension services for farmers than public bodies, the latter often not willing or able to provide enough funds for different reasons depending on the context of a country [9]. Second, agri-business-linked extension workers seem to reach more growers than non-business extension workers. In our study, an average business-linked extension worker handled 292 farmer queries on plant health problems per year, versus 182 queries done by a non-business-linked plant doctor. The primary reach was 94 vs. 66 different growers per extension worker per year. Such differences in reach were not found in a previous study of Zhang et al. [7] from China, indicating that there may be differences between different regions of China. In our study, growers visited agri-business-linked plant doctors about twice as often as the growers visiting non-business plant doctors. As for private extension workers, the plant clinics are normally located where personnel are based within their daily duty, i.e., in their agri-input shops. In this way, it is more convenient for them to hold clinic sessions than it is for the governmental extension workers. Moreover, input shops are already familiar to growers as points for advisory support, whereas plant clinics of governmental bodies need to be effectively advertised to increase growers' awareness of the clinics' existence and operating schedule [20,36]. The rate of growers visiting a plant doctor only once and never again was much higher for non-business-linked plant doctors than for visits of agri-business-linked doctors, the latter being usually more repeatedly, thus regularly visited. This might be because non-agribusiness plant clinics are sometimes mobile clinics going from one grower hot spot to the next, and thus are less regularly held at the same location, whereas the agri-business-linked plant clinic always runs at the same location, i.e., in or next to an agri-input dealer or agri-service shop. In any case, reach of both extension worker types is good and larger than in other countries such as in Uganda [37], or Zambia [45]. In a number of countries, it is also difficult to maintain plant clinic attendance, such as in Zambia and Tanzania (S. Toepfer, 2014, own observation), something that seems less the case in China.

## 5. Conclusions

In conclusion, extension services seem of good quality, regardless of type, but all here-studied extension worker types heavily favor pesticide-based advice. There is limited evidence for conflicts of interest from a grower perspective as input costs of growers as well as profits were comparable. However, consumers and the environment may suffer from slightly higher risks through agri-business-involvements of agri-input sales due to slightly more pesticides applied. Nevertheless, it became clear that improvements in agricultural extension services must generally reduce the overreliance on pesticides regardless of the type of extension service worker and his/her business involvement. In addition, some care must be taken when considering a private-sector approach in agricultural extension services through analyzing whether the advantages (more sustainable service, potentially better outreach) weight more than the disadvantages (more pesticides advised, slightly higher risk) [1,46]. Particular care should probably be taken when the private sector is a) exclusively linked to agri-input sales [23] and not to other models



like farmer association-based advice, and b) would have the monopoly in extension [3,8,9]. In the end, it remains the responsibility of the countries and societies [47,48] to analyze their own extension systems with regard to advisory service quality and the potential risks of involving the private sector in delivering such services. A good data management system, such as the here-used Plantwise system, may help in such analyses. Our findings will hopefully help to judge the advantages and disadvantages of the countries' different approaches in providing agricultural extension services to growers and to improve plant health systems across the globe.

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