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Farmers' adoption of agricultural innovations: A systematic review on willingness to pay studies

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Abstract

Unlike most studies that focused on specific innovations, this study systematically analyzed farmers' adoption of agricultural innovations in general. It reports willingness to pay (WTP; willingness to accept (WTA)) as a proxy for adoption, its determinants, applied methods, and statistical models. After searching and screening, 80 studies qualified for review. Majority ($n = 30$) of studies focused on farmers' WTP for innovations in agricultural water provision or environmental and crop protection ($n = 35$), while the remaining studies handled crop or animal improvement innovations. Most studies were performed in developing countries, using stated preference methods for economic valuation, with 55% of the studies ($n = 44$) applying contingent valuation compared to 39% taking choice modeling approach. While farmers are generally willing to pay premium for improvement in agriculture technologies, WTP (WTA) depends on the innovation (system). For example, premiums ranged from about 0.125 to 2 USD/m^3 of water depending on water supply (e.g. ground vs. surface water). Furthermore, the determinants of farmers' WTP can be grouped into sociodemographic, biophysical, technological, institutional, and behavioral factors. As illustrated by relatively high WTP, the review demonstrates that farmers embrace most innovations, regardless of the context and methods applied.

Keywords

Agricultural innovations, economic valuation, premium, willingness to accept, willingness to pay

Introduction

The importance of sustainable agricultural production in improving and maintaining the health of humans, animals, soil, and environment has been well-documented. For example, organic and conservation agriculture have been fronted as protective to the soil (Siddique et al., 2012). Planting companion crops to tackle the challenges of stem borers in grains, weeds, and degraded soil has been demonstrated to increase grain yield sustainably (Khan et al., 2014). Such innovations in agricultural production have huge potential to increase food production and improve health and nutrition as well as maintain environmental integrity (Carletto et al., 2015; Welch and Graham, 2005). Nevertheless, their adoption by farmers, especially smallholder farmers in developing countries, has been slow and low (Kabunga et al., 2012; Mausch et al., 2018). Innovations can be broadly defined as new, more effective or better technologies, tools, processes, concepts, information, ideas, or actual practice employed to produce goods and services (Bigliardi and Galati, 2013; Glover et al., 2016). Here, agricultural innovations are considered as technological advances or processes (farming practices) that can substantially improve yield and the production function (Feder and Umali, 1993), or natural capital (e.g. soil quality), and food and nutrition security.

The adoption of innovations is complex and involves a mental process that highly depends on the innovativeness of the receiver (Rogers, 1995). Thus, farmers' adoption of innovation depends on personal and social characteristics and the need for the innovation, among many other factors (Kamrath et al., 2019; Meijer et al., 2015; Rogers, 1995). Regarding the factors that aid adoption of agricultural innovations, however, literature has remained rather inconclusive. A number of studies have considered different determinants as important in adoption decisions by farmers (Kabunga et al., 2012; Pannell et al., 2014). The failure to

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find unequivocal determinants of adoption could be related to the complex interaction of factors that influence farmers' decision-making (Aubert et al., 2012; Meijer et al., 2015) and the wide variety of methodological approaches applied by the researchers. The currently existing review studies on adoption of agricultural innovations have specifically examined single types of innovations, such as agroforestry (Mercer, 2004), precision agriculture (Tey and Brindal, 2012), agricultural management (Baumgart-Getz et al., 2012), and conservation agriculture (Knowler and Bradshaw, 2007; Pannell et al., 2006). Without neglecting the contributions of these innovation-specific reviews, a more comprehensive review on all types of agricultural innovations is needed to better understand the motivation for adoption. More than two decades ago, Feder and Umali (1993) carried out such a review, though in a non-systematic way, which is known to increase the risk of selection bias (Wong et al., 2008). In addition, many of the reviews did not consider the methods used to explain adoption.

This study aimed at conducting a systematic review on farmers' adoption of agricultural innovations. Due to the wide diversity of measures reported in farmer adoption literature, our study specifically focused on economic valuation studies, that is, studies that elicit farmers' willingness to accept (WTA) or willingness to pay (WTP) for innovations that they have adopted (*ex post*) or are intending to adopt (*ex ante*). As the uptake of agricultural technologies often requires willingness and financial ability of farmers, WTP/WTA is considered as an important proxy for adoption (intention) of an innovation (Matuschke et al., 2007; Tey and Brindal, 2012). This approach is especially useful in a developing country's context where (smallholder) farmers may have preferences for certain (aspects of) innovations but often fail to adopt them due to financial constraints (Collier and Dercon, 2014; Douthwaite et al., 2001).

Our study differs from past reviews on adoption of agricultural innovations in three ways: (1) it offers the first systematic review on adoption of agricultural innovations by farmers while looking at the wide spectrum of agricultural innovations. As such, it helps to compare determinants that are consistent across different types of farm innovations; (2) it focuses on farmers' WTP/WTA as an important proxy of adoption; and (3) it provides insights in the variety of economic valuation methods and the statistical models used to, respectively, analyze WTP and its key determinants.

Methods

Study selection

The scope of this review on farmers' WTP (WTA) was intentionally broadened to capture the breath of agricultural practices that are innovative in nature, without specifically relying on one type of innovation.

Articles published up to January 2019 were searched from Web of Science using combinations of key words and their synonyms. We relied upon a broad list of key words based on previous reviews and articles that cover (related) topics of farmers, WTP (proxy for adoption), and agricultural innovations. We did not identify any studies that provided a systematic review on farmers' WTP/WTA as a measure of adoption of agricultural innovations.

The key words for farmers included: Farmer* OR "farming household*" OR "primary producers" OR landholder* (Osborne et al., 2012; Pannell et al., 2006, 2014). The key words for WTP/WTA, which were extended with synonyms for adoption to ensure that all economic valuation studies were included, are: adopt* OR accept* OR choice OR choos* OR preference* OR "willingness-to-pay" OR similar OR "willingness to accept" OR similar OR "willingness-to-adopt" OR similar (De Steur et al., 2016; Lewis and Pattanayak, 2012; Or and Karsh, 2009; Peek et al., 2014). The key words for agricultural innovations were based on the works of Andersson and D'Souza (2014), Baumgart-Getz et al. (2012), Knowler and Bradshaw (2007), Rosenstock et al. (2016), and Tey and Brindal (2012) and included innovation* OR intervention* OR technolog* OR "improved variet*" OR "plant variet*" OR "high yielding variet*" OR bioforti* OR similar. The search resulted in a total of 8180 references that were subjected to screening.

Screening process

While this study aimed at providing a comprehensive overview of farmer adoption studies, only studies that conform to the following main inclusion criteria were included: (1) the study was done at a farm level, looked at adoption of innovations by farmers; (2) the study is original (collected primary data) and written in English; (3) the study employed quantitative or mixed methods of research; (4) the study reported WTP (e.g. full price or premium) and methods used to measure WTP/WTA as well as statistical techniques; and (5) the study looked at WTP for agricultural practices or technologies, which are innovative in nature (see background for definition of innovation). As a consequence, articles targeted toward traditional agricultural practices, such as crop rotation, intercropping, or mulching, were excluded from the review, unless they have an innovative component in them (e.g. use of intercropping in integrated weed management). In addition, studies looking at the impact of the innovation (e.g. yield increase) or adoption intensity (e.g. number of technologies adopted) were excluded. Two researchers with expertise in agricultural sciences worked separately and together to decide on whether or not a particular practice reported in each article has innovative components that could qualify them for inclusion. Table 1 presents the inclusion and exclusion criteria used in the eligibility screening.

Figure 1 shows the search and screening stages for the articles. Out of 8180 articles that were initially obtained, 5 duplicate references were removed and 6966 articles were removed after evaluating their titles, because they were not related to innovation adoption by farmers or they were reviews; 1097 articles were not eligible after studying their

Table 1. Criteria for inclusion and exclusion of references.

PICOS	Inclusion criteria	Exclusion criteria
Population	Farmers	Consumers, processors, and others
Intervention	Farm-level innovative agricultural practices/ technologies	Nonfarm-level practices, e.g. off-farm processing and marketing
Comparator	Traditional agricultural technologies/ practices	None
Outcome	WTP/premium and determinants	Adoption without WTP measure
Study design	Economic valuation (WTP/WTA) methods and models for evaluating determinants	None

WTP: willingness to pay; WTA: willingness to accept.

abstracts. The remaining 112 articles were subjected to a full-text screening and were assessed for inclusion (see inclusion criteria in Table 1). At this stage, 32 references were removed for different reasons as specified in Figure. 1. This resulted in 80 articles that were included for analysis.

Data extraction and analysis

Key data were extracted from each study in line with the objectives of this review. The data extraction sheets captured the characteristics of the studies (e.g. authors and year), the agricultural innovation(s) studied, the methods and models employed to investigate farmers' WTP, the reported average values, and the significant determinants of WTP/WTA. For further analysis, we particularly examined the results section of each article and especially the tables of statistical outputs to evaluate the significance of the variables and the direction of influence. Given the broad search employed in this review, articles that qualified for the review were not homogenous in the units used to express WTP and the methods, even within the same type of innovation. This made comparison across studies difficult and limited further analysis, also as indicated by Pandey et al. (2016) leading to a narrative, rather than meta-analysis. For the determinants of WTP/WTA, we classified the factors into five categories across all studies. For simplicity reasons, the terms WTP and WTA have been used interchangeably in the review, to refer to economic valuation, that is, the value that farmers place on certain (aspects of) innovations. While WTP and WTA are both economic valuation terms, we understand that some difference exists between them. We did not consider this difference as an objective in this study as it has been widely studied.

Results

Study characteristics

The study characteristics of the 80 selected studies are summarized in Table 2. In terms of type of innovation, most of the studies focused on innovations targeted toward environment and crop protection ($n = 35$), for example, agri-environmental schemes or payment for ecosystem services (PES), followed by improvement in agricultural water supplies (30 studies) and then crop and animal improvement innovations ($n = 15$). Majority of the studies were conducted in developing countries ($n = 58$) as compared to developed countries ($n = 22$). Among the former, Ethiopia dominated with seven studies, followed by India (five) and Kenya (five). For the developed countries, study locations were mainly situated in the United States (five studies), Spain (four), Germany (three), and Italy (three).

Methods of assessment of WTP

The methodologies applied in terms of economic valuation and analytical methods are presented in Table 3. Most of the studies employed stated preference (SP) methods for eliciting farmers' WTP/WTA for agricultural innovations. In quantitative terms, 44 studies applied direct valuation (contingent valuation) method, while 31 studies applied the choice modelling approach. Furthermore, different types of regression models have been used to investigate the influence of various factors on farmers' WTP for agri-innovation, depending on the type of data (outcome measured). Analytical methods mostly applied include logistic regression, probit, latent class, and tobit models. Other less common statistical methods used include linear regression, linear (non) programming models, Monte Carlo simulation model, and hedonic model.

Variation in the measures and values of WTP

Farmers were generally willing to pay for agricultural innovations but premiums differed among the types of innovation studied. The studies that investigated farmers' WTP for improvement in agricultural water supply mainly measured WTP in terms of the amount farmers are willing to pay for a given volume of water supplied or the amount of farmland to be irrigated. A critical look at these studies reveals that majority of farmers are prepared to pay a premium in a range of 0.1 to 2.0 USD per cubic meter of irrigation water (Table 3). In case of innovations aimed at protecting environmental integrity, both WTA to conserve the environment and WTP for innovations that result in environmental safety production or protection against weather shocks are measured, all in variable ways. For instance, farmers are willing to accept between US$50 and 200 per acre for PES (Kaczan and Swallow, 2013). For crop improvement innovations, WTP is sought for improved seeds or varieties to plant a given amount of acreage. For instance, genetically modified (Bt) cotton was valued at US$48/ha in Argentina (Qaim and De Janvry, 2003), while Bt eggplants were approximately US$66/acre in India (Krishna and Qaim, 2007).

Determinants of farmers' WTP/WTA

The determinants of WTP by farmers largely depend on the type of innovations studied. However, through this review,

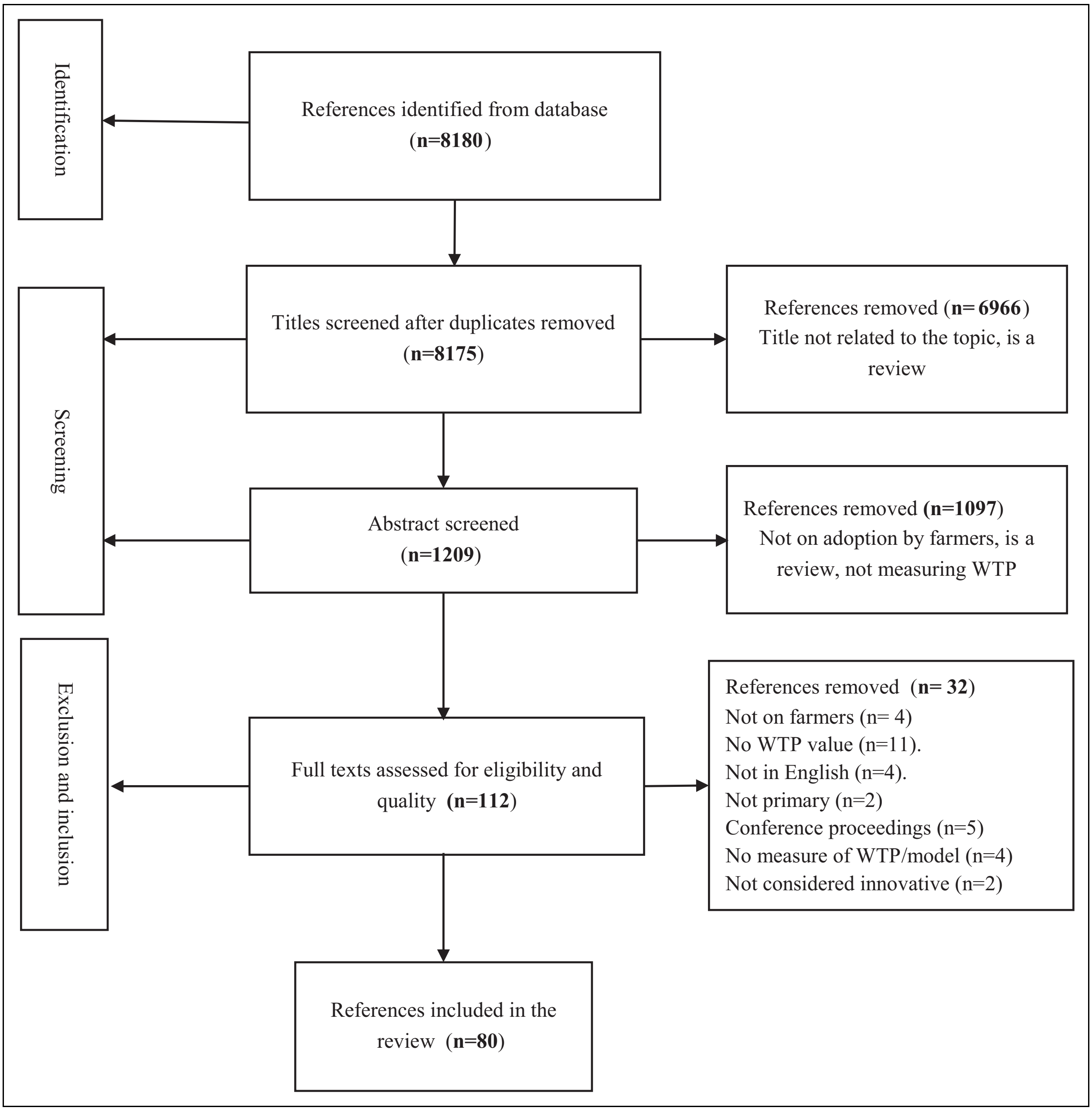

Figure 1. Diagrammatic flow of selected studies through the screening stages. WTP: willingness to pay.

we scouted common groups of determinants across the studies. As shown in Table 4, we categorized the determinants into five major groups (sociodemographic, biophysical, technological, institutional, and psychological and behavioral factors), in line with the typology of Tey and Brindal (2012). Table 5 further provides the summary of significant determinants across agricultural innovation studied.

Sociodemographic information relates to the farmers' individual characteristics (e.g. age, sex, and level of education) or that of the farmers' household (e.g. household size and income). In the studies reviewed, the most significant factors reported are education, age, gender, household income, and farming experience. While the majority of studies found positive influence of education on WTP/WTA, the influence of age has produced mixed results, with most studies indicating that younger farmers tend to pay more than the older ones. Also the level of income produced positive influence on WTP, with wealthier farmers willing to pay relatively higher premium. Family size, often related to the amount of labor for farmwork, produced mixed effects, as did gender.

Biophysical factors are the agro-ecological factors that include on-farm natural and physical properties (e.g. land and vegetation) and operational factors (e.g. acreage farmed). Under this, land owned, cultivated area and production per unit area were studied across all the innovation categories, producing positive effects on WTP/WTA. Other significant agro-ecological factors, which were more innovation specific include previous weather shocks (e.g. dry spell), water quality (salinity and Ph), sources of water (ground or surface), irrigated area, and frequency of

Table 2. Summary statistics of studies included in the review.

Characteristics	Number of studies
Type of agricultural innovations	
Agricultural water provision	30
Environmental and crop protection technologies	35
Crops and animal improvement technologies	15
Level of economic growth	
Developing countries	58
Developed countries	22
Country of study	
Ethiopia	7
India	5
Kenya	5
United States	5
Spain	4
Germany	3
Italy	3
South Africa	3
Ghana	3
Others (≤2 studies)	42

irrigation. Dry production season and previous weather shocks positively motivated farmers to pay for water- and environment-related innovations.

Technological factors are the characteristics of the technology or innovation, such as the cost, usefulness, or the ease of use (Douthwaite et al., 2001). The cost or price involved in innovation was studied across all categories of innovations and produced a negative effect on WTP/WTA. The ease of use, usefulness, and amount of improvement in the technology have positive effects on farmers' WTP. In the case of environmental and crop improvement innovations, the environmental adaptability (e.g. drought resistance) was found to positively affect farmers' WTP.

Key institutional factors that were found to be significant refer to the access to information (e.g. from extension workers), credits, and remittance. The availability of incentives to conserve the environment was also found significant (Tables 3 and 4). All these factors have been found to positively affect WTP/WTA by farmers.

Psychological and behavioral factors deal with the psychological state (e.g. intention to try) of farmers and their subjective evaluation of innovative agricultural practices, often operationalized through their attitude toward the innovations (Buckley et al., 2012). Perceived risks and risk aversion produced negative effect, while trust in service providers, risk awareness, positive attitude, satisfaction, and expectation of future value generated positive effects (Table 4).

Discussion

The aim of this systematic review was to provide insights into farmers' WTA/WTP for innovations at farm level. It specifically looked at the methods applied (economic valuation and statistical techniques) and common determinants of WTP across categories of agricultural innovations. It offers the first systematic review of farmers' WTP/WTA as a proxy for adoption of agricultural innovations. Most existing studies on adoption of agricultural innovations consider a specific type of innovations. We have taken a different direction by looking at a large range of innovations. As the results are not linked to a specific innovation, our approach takes the advantage of providing more comprehensive results. For example, we provide the most significant determinants of farmers' WTP/WTA, across different innovations. Due to our wide approach, however, caution is needed when comparing different innovations.

Majority of the studies have been carried out in developing countries. This is in line with the focus of the sustainable development goals (SDGs), which predispose that innovations, including those in agriculture, have to be transferred from developed to less-developed countries (Stafford-Smith et al., 2017). The developing nations have lagged behind in adoption of agri-innovations, which would be important in realizing the SDG number two, which focuses on eliminating hunger and food insecurity while promoting sustainable agriculture (Mugambiwa and Tirivangasi, 2017). Thus, there is need to promote adoption of farm-level innovations in developing countries, where agriculture remains the main pillar for economic growth (Adenle et al., 2018). Through this review, insights have been provided on the factors that need to be considered to promote adoption of such innovations. The fact that most of the studies have focused on water supply and environmental-related innovations shows the importance of these factors in sustainable food production. In fact, the water, energy, and food nexus has been proposed as a key strategy to achieve sustainable food production and is acknowledged in a number of SDGs (Giupponi and Gain, 2017). In view of the SDGs and the role of agriculture in reducing hunger and malnutrition, however, future research also need to focus (more) on understanding farmers' WTP to adopt those innovations that directly increase food production. The findings regarding the specific objectives of this review are discussed below pointing out the possible areas for further investigation.

The role of methods

Approaches for measuring WTP or WTA (economic valuation) can be placed in two broad categories: the revealed preference (RP) and the SP methods. Most of the studies reviewed could have applied SP methods because these methods are able to estimate both the use and the nonuse values of a product or a service, compared to the RP approaches that measure only the use values (Bozorg-Haddad et al., 2016; Saldías et al., 2016). In fact, most studies measured WTP for water and environmental improvement innovations. Both types of innovations contain and require measuring nonuse values (e.g. sustainability of irrigation water innovations), making them suitable avenues for application of SP methods. In addition, such approaches are direct and do not involve monetary incentives or a lot of logistics to provide the actual product during the WTP estimation (McIntosh et al., 2013). However, when applying these (SP) methods, one has to be

Table 3. Methods applied and outcome of farmers' WTP/WTA agricultural innovations.

Technology	Country	Type of farmers	Sample	Method for WTP/WTA	Statistical technique	Determinants of WTP/WTA	WTP/WTA (premium)	Reference[a]
Agricultural water improvement technologies and practices								
Improved water supply	Palestine	Those doing irrigation	150	CVM	Multiple linear regression	Prices, irrigation area, farm income, and irrigation frequency	US$0.125/m^3.	1
Water supply reliability	Spain	Irrigation communities	299	CE	Mixed logit	Water supply, water measure, and price	0.35 s/m^3 (50% premium)	2
Efficient irrigation	Turkey	Males in WUAs	461	CVM	Tobit	Education, modern irrigation, crop, marital status, property ownership, and gravity irrigation	US$133.7/ha (US$0.013/m^3)	3
Recycled irrigation water	Greece	Full-time and part-time farmers	107	CVM	MNLM	Gender, education, income, cultivated area, and water shortage	Half of fresh water price	4
Surface water reliability	Pakistan	Cotton, rice, and sugarcane farmers	561	CE	RPL	Water salinity, reliability, groundwater sources, and costs	Rs. 150–700/acre	5
Bundling water with non-water services	Uzbekistan	Farmers in WUAs	103	CE	Conditional and mixed logit	Cost, school, microcredit, and health	US$1.64/1000 m^3 to US$6.86/1000 m^3	6
Reliability in agricultural water	Ireland	Farmers who irrigate	200	Probabilistic optimization	Nonlinear programming and Monte Carlo	Price, water shortage, type of irrigation, and crop type	0.168 currency units per cubic meter	7
Tank irrigation systems	India	Low or middle income	62	CVM	Logit	Family labor, area under rice, water requirement, and season (wet or dry)	INR 218.50/ha/year	8
Groundwater quality	Lebanon	Local farmers	138	CVM	General linear regression	Land ownership, production, source of water, and education	102 US$ /166.67 US$/year	9
Irrigation water trading	Spain	Irrigators and nonirrigators	241	CVM	*t*-test and Chi^2 test	Perception of water as nontradable, trading experience, and drought	0.17 EUR/m^3–0.21 EUR/m^3	10
Irrigation water availability	Iraq	Farmers in secured (high rainfall) and nonsecured zone	236	CVM	Probit	Bids, water deficit, source, cultivated area, education, age, and agricultural activity	11.49 USD/10 m^3–20.28 USD/10 m^3	11
Precision water quality	The United States		828	CVM	Probit	Abatement levels, belief, gender, employment, and education	US$46.97 (10% abatement) and US$ 49.94 (20%)	12
Groundwater sources	Iran	Water traders	330	RP (market data)	Heckman and probit	Water market, using other wells, jobs, fragmented plots, age of trees, land, water level, and pH	1860.45 IRR/m^3	13
Irrigation water reliability	Ethiopia	Nonirrigators	210	CVM	Choice and latent variable	Future irrigation, experience, income, and dependency	ETB 1,531,000–1,557,000	14
Guaranteed water supply	Spain	Irrigators	150	CVM	Tobit	Age, income, training, household size, olive trees/ ha, and water quota	€0.39/tree (5-year guarantee) and €0.74/ tree (9 years)	15
Wastewater treatment	Kenya	Urban farmers	80	CE	RPL	Quality and quantity of water, ecosystem restoration, age, education, gender, employment, health, and risks awareness	Kshs.90.57/month	16

(continued)

Table 3. (continued)

Technology	Country	Type of farmers	Sample	Method for WTP/WTA	Statistical technique	Determinants of WTP/WTA	WTP/WTA (premium)	Reference[a]
Wastewater reuse frameworks	South Africa	Smallholders	45	CE	Logit and LCM	Trust for service providers, water quality, and level of restrictions on use	ZAR 2.37/ m^3	17
Groundwater resources	Jordan	All farmers		Linear programming	Linear programming	Price, quantity, and effect on production	US$ 0.35/m^3	18
Water restoration	Bolivia	Urban and rural farmers	399	CVM	Logit	Cost, knowledge, and satisfaction with water supplies	US$17/ha annually	19
Water right systems change	South Africa and Tunisia	Farmers in WUAs	62	CVM	Ordered logit and Hanemann	Water rights, duration, quality of title, price, agent based, and market transfers	0.0143 TND (Tunisia), 0.024–0.146 Rand/m^3 (South Africa)	20
More units of irrigation water	Morocco	Smallholders	95	CVM	Tobit	Surface or groundwater supply, season, age, and cost	0.88–2.75 DH/m^3	21
Sustainable irrigation water	China	Rural farmers	600	CVM	Logit	Family size, income, and water supply (surface or ground)	80.4 RMB/mu/year	22
Improved water supply	Ethiopia and Sudan	Smallholders	200	CE	Mixed logit	Irrigation frequency, price, water-saving, and transboundary cooperation	US$ 0.7–US$ 1.6/ha	23
Irrigation water in high rainfall area	Mexico	Banana farmers	51	Net income change	Productivity change	Farm size, revenue, irrigated area, yield, and production cost	1.48–1.75 USD/m^3	24
Smallholder irrigation schemes	South Africa	Smallholders	124	CVM	Residual return	Gross margin, type of farmer, and irrigation scheme	R 0.01–0.19/m3	25
Efficient irrigation water	China	Rural farmers	300	CVM	Regression	Family size, income, and attitude	1021 RMB/ha/year	26
Sustainable irrigation	Turkey	Smallholders	675	CVM	Probit and logistic	Age, education, land ownership, modern irrigation, and training	170.6/year	27
Water saving measures	Lebanon	River basin farmers	150	CE	Conditional and mixed logit	Income, education, age, price of water, water saving, and water metering	0.22–0.32 USD/m^3	28
Surface water for irrigation	Algeria	Irrigating farmers	112	CVM	Ordered logit	Farm ownership, access to groundwater, cropping pattern, training, and risk exposure	4.11 DA/m^3,	29
Surface water for irrigation	The United States	Large-scale farmers	199	CVM	Double-bounded dichotomous choice	Groundwater, water shortage, conservation program, and experience	2.7 USD/Cm^3	30
Environmental and crop protection technologies								
Conservation agriculture	Ecuador	Rural farmers	331	CE	RPL	Yield, planting labor, weeding labor, and erosion	0.11–1.77% of production cost	31
Weather-indexed crop insurance	Bangladesh	Male and female farmers	433	CE	Probit	Gender, trust technology, and financial literacy	Flood (US$11.64–13.70); hail (US$10.19–12.58); and wind (US$11.0–13.15)	32
IPM	Nepal	Smallholders	292	CVM	Probit	Awareness, pesticide levels, education, gender, and income	US$25.23/year	33

(continued)

Table 3. (continued)

Technology	Country	Type of farmers	Sample	Method for WTP/WTA	Statistical technique	Determinants of WTP/WTA	WTP/WTA (premium)	Reference[a]
Rainfall-based indexed insurance	Ethiopia	Smallholders	310	CVM	Probit	Moisture stress, education, worry of weather, credit, income, and remittance	Birr 119.90/year/ha of maize	34
Riparian buffer zones	Ireland	Farmers in water catchment	247	CVM	Tobit interval	Economic, attitudinal, and farm structural factors	€1513/ha	35
Soil conservation	India	Crop farmers	250	CVM	MNLM	Cropped area, farm size, income, family size, and age	Rs. 4687/ha (US$78.1/ha)	36
BMPs	The United States	Large-scale farmers	85	Conjoint analysis	Weighted least square	BMPs that are familiar, simpler, and easy to integrate in existing practice, incentives	US$85.99–349.48/acre	37
Agri-environmental conservation	Italy	Cereal farmers	449	CE	Parametric and semi-nonparametric models	Production cost, returns, and risk perception	US$125/ ha	38
IPM	Philippines	Farmers using pesticides	176	CVM	Logit	Environmental risks, information, farm size, and awareness	551–680 pesos/season	39
Green fertilizers	Germany	Home gardeners	504	CE	Hierarchical Bayes estimate and LCM	Fertilizer type, price, brand, labeling, and nutrient values	€6–12/2.5 kg pack	40
Urban waste compost	Ghana	Urban and peri-urban farmers	700	CVM	Probit	Experience, ability to pay, soil inputs, farming systems, and urban vs. peri-urban	US$ 0.1–3.0/50 kg bag	41
Environmental schemes	Belgium	Farmers under "late mowing and reduced use of farm inputs"	141	CVM	Probit	Awareness, revenue index, livestock density, and low productivity meadows	198€ in less favored agricultural area and Euro 372 other areas	42
Low-toxicity pesticides	Nicaragua	Smallholders	433	CVM	Logit and log-linear	Experience with poisoning, income, and current exposure to pesticides	28% premium	43
Integrated weed management	Iran	Wheat producers	180	CVM	MNLM	Income, irrigated area, yield loss, weed resistance, and rain-fed cultivation	US$ 26.26/ha	44
Soil and water conservation	India	Rain-fed farmers	60	CVM	Logistic	Qualification, income, irrigation experience, age, dependency, market, and livestock	US$1302.2 or 1207 labor days/month	45
Improved weather-indexed insurance	Ethiopia	Rural households	1400	CVM	Hedonic model	Education, age, gender, wealth, risk aversion, consumption risk, price, and insurance	10–40 Birr/month	46
PES	Tanzania	Smallholders	77	CE	LCM	Annual cash payment to individual farmers and upfront manure payment	US$59.6–78.6 individual payment and US$140 for manure fertilizer	47
Mesoscale weather information	The United States	Large-scale farmers	175	CVM	Maximum likelihood regression	Sales, irrigated area, weather losses, and raw data/value-added weather information	US$5.83 (raw data) and US$ 6.55 (value added)	48

(continued)

Table 3. (continued)

Technology	Country	Type of farmers	Sample	Method for WTP/WTA	Statistical technique	Determinants of WTP/WTA	WTP/WTA (premium)	Reference[a]
BMP-water quality	Canada	Farmers in watersheds	204	CE	Mixed logit	Age, farmers' experience, and costs	US$0.54–1.10/acre for 1% phosphorus and US$ 0,43–1.28 coliform reduction	49
Green revolution	Ghana	Maize farmers	30	CE	RPL	Attributes, location, food-security, and gender	6.26–30.06 US$/acre	50
Weather-indexed insurance	Ethiopia	Smallholders	460	CVM	Probit	Education, farm size, production, coping strategies, risk aversion, and drought shock	276.7 birr	51
Water-related ecosystem services	Kenya	Farm households	229	CE	Mixed logit	Ecosystem services, information, experience in agroforestry, farm size, and income	US$2.44 (Riparian); US$135.37 (environment-friendly farming); and 7.70 (reforestation)	52
Biodegradable mulching films	Italy	Horticultural farmers	107	CVM	Independent *t*-test	Price, strength, durability, mechanical harvesting, transparency, age, education, and agronomic performance	464.11 (€/ha)	53
AES	Spain	Irrigated and nonirrigated farm	295	CE	LCM	Cover crops area, crop management, ecological focus areas, collective participation, and incentives	€8–9/ha/1% EFA	54
Crop weather insurance	Bangladesh	Maize farmers	120	CE	RPL	Climate change skepticism, insurance provider, and type of insurance	6.64US$/0.13 ha (private providers) and 2.8–6.52US$ (hailstorm)	55
Aflasafe	Nigeria	Smallholders	492	CVM	Logit and OLS	Credit, extension, awareness of aflatoxin, education, household size, expenditure, and location	13.01–13.04 US$ (experienced farmers) and 3.55–7.46 US$(otherwise)/10 kg	56
Faecal sludge and solid waste compost	Uganda	Smallholders	275	CE	MNLM and LCM	Status of compose, price, household size, gender, experience, and product reservation	0.127–0.4 USD/kg	57
PES	Burkina Faso	Smallholders	300	CE	Logit, LCM	Type of intervention (wastewater, organic matter, and drip irrigation) and costs	US$302.4 (drip irrigation) and US$191.5 (organic matter)	58
Ecosystems services in watershed	Chile	Smallholders	105	CE	Conditional logit	Age, education, income, land ownership, water quality, storage and availability, and condition of flora and fauna	10.06 USD/month	59
Climate adaption programmes	Nepal	Smallholders	720	CE	RPL	Varieties, soil quality, irrigation, age, extension, drought, flood proneness, and perception	USD 10.81–16.41	60
Targeted staggered pest control	Benin	Cotton farmers	300	CVM	Interval regression	Education, area owned, percent cotton area, and preference	25.8 euro/year	61

(continued)

Table 3. (continued)

Technology	Country	Type of farmers	Sample	Method for WTP/WTA	Statistical technique	Determinants of WTP/WTA	WTP/WTA (premium)	Reference[a]
Watershed conservation	Tanzania	Smallholders	360	CVM	Probit	Marital status, distance to water, household size, income, and price of irrigation	Tanzanian shillings 22,261.8	62
Biodegradable mulching films	Italy	Horticultural farmers	107	CVM	Heckman's sample	Film type, nonfarm job, durability, and strength of film	200–750 euro/ha	63
Climate smart agriculture	Nigeria	Smallholders	1138	CE	Random effect and mixed logit	Land tenure and property right, payment method, incentive, and type of crop	122 USD/ha (GAP with manure) and 22.2 without manure	64
Bio-based fertilizers	Belgium, Denmark, France, the Netherlands, Germany, Hungary, and Croatia	Large-scale farmers	555	CE	RPL and LCM	Price, form of fertilizer, volume, uncertainty of Nitrogen, organic carbon, nutrient release, hygienic fertilizer, information, age, perceived advantage, and manure treatment	33.2% of price of chemical fertilizer	65
Crop improvement technologies and practices								
Crop variety traits	Ethiopia	Smallholders	131	CE	RPL	Adaptability, yield stability, resource endowment, experience, and extension	17.49–294.52 Ethiopian Birr	66
New upland rice varieties	Ivory Coast	Rice farmers	250	CVM	Hedonic model	Production and consumption characteristics, and variety	265 CFAF/kg (replanted) and 91 CFAF (nonreplanted)	67
Herbicide-coated imidazolinone-resistant maize	Kenya	Smallholders	60	CE	Linear regression	Price and cob color	US$1.79/kg	68
Bt eggplants	India	Poor farmers	360	CVM	MNLM	Price, income, farm size, household size, and education	Rs. 4642/acre (US$ 67)	69
Cotton yield monitor	The United States	Large-scale farmers	743	CVM	Probit	Experience with precision tech, price, use of computers, cost perception, and adopters	US$ 6609.9, 8899.0	70
Hybrid wheat	India	Smallholders	281	CVM	Constant-only bid function and probit models	Prices, information, and credit	847 rupees/acre	71
GM (Bt) cotton	Argentina	Cotton farmers	299	CVM	Log likelihood	Price, arable land, education, and information access	US$48/ha	72
Improved cassava varieties	Ghana	Smallholders	450	CE	Mixed logit and LCM	Disease resistance, longevity of roots, multiple uses, price, and productivity	₵ 83.59 (more year in soil) and ₵ 45.00 (disease resistance)	73
Transgenic sorghum	Burkina Faso	Sorghum farmers	150	CE	LCM	Price, seed source, expected yield, days to maturity, risk-aversion, production, and seed saving	4953 CFA/kg	74
Improved quinoa varieties	Peru	Smallholders	458	CE	MNLM	Yield, mildew resistance, food security, taste, maturation period	49 PEN/kg (higher yield) and 81 PEN (resistance)	75

(continued)

Table 3. (continued)

Technology	Country	Type of farmers	Sample	Method for WTP/WTA	Statistical technique	Determinants of WTP/WTA	WTP/WTA (premium)	Reference[a]
Improved corn seeds	Mexico	Smallholders	200	CE	MNLM and LCM	Yield, disease resistance, larger ear size, and price	2.7–39.9 USD/20 kg bag	76
Animal production technologies and practices								
GMO-free milk production	Germany	Large-scale farmers (>100 acres)	151	CE	Logit and LCM	Attitude, market potential, prices, age, education, and feeding regimens	0.80 euro/kg milk	77
Animal genetic resources conservation	Ethiopia and Kenya	Livestock keepers	370	CVM	Tobit	Production system, cattle number, awareness, importance of crossbreds, age, and exotic breeds	€7/animal/year (Ethiopia) and €50/animal/year (Kenya)	78
Genotyping in dairy production	Canada	Dairy farmers	159	CVM	Mixed logit	Risks attitude, social interactions, mastitis concern, belief in genomics, and experience	50 USD/animal	79
Artificial insemination hub	Kenya	Smallholders	301	CE	RPL	Price, service providers, sexed semen, local semen, payment system, experience, milk sold, hub access, income, and education	22.84 USD/service	80

WTP: willingness to pay; WTA: willingness to accept; WUA: water user association; IPM: integrated pest management; BMP: best management practice; PES: payment for ecosystem services; AES: agri-environmental scheme; GM: genetically modified; GMO: genetically modified organism; CVM: contingent valuation method; CE: choice experiment; LCM: latent class model; MNLM: RP: revealed preference; multinomial logit model; RPL: random parameter logit model; OLS: ordinary least square.

[a]The full reference list for the studies described in Table 3 can be found in the online supplementary file. The number of the individual reference in the table is matching with the numbers given to them in the supplementary document.

Table 4. Categories and effects of significant factors on farmers' WTP/WTA for agricultural innovations.

Categories of determinants	Significant variables	Effect	References[a]
Water improvement technologies			
Sociodemographic factors	Education	Positive	(Alcon et al., 2019; Aydogdu, 2016b)
	Age	Inconclusive	(Harun et al., 2015)
	Married	Negative	(Aydogdu and Bilgic, 2016)
	Gender—female	Negative	(Akter et al., 2016)
	Employment	Positive (employed)	(Hite et al., 2002; Ndunda and Mungatana, 2013)
	Income	Positive	(Kassahun et al., 2016)
	Family size and labour	Positive	(Chandrasekaran et al., 2009)
	Farming experience	Positive	(Knapp et al., 2018)
Biophysical factors	Irrigated area	Positive	(Abu-Madi, 2009)
	Yield/production	Positive	(El Chami et al., 2008)
	Land endowment and cultivated area	Positive	(Aydogdu and Yenigun, 2016)
	Water source	Positive (groundwater)	(El Chami et al., 2008)
	Water quality	Positive	(Bell et al., 2014)
	Season/water shortage	Positive (dry season)	(Bakopoulou et al., 2010)
	Amount and frequency of water	Positive	(Abu-Madi, 2009)
Technological factors	Cost of irrigation/water	Negative	(Alcon et al., 2014)
	Type of irrigation	Negative (gravity irrigation)	(Aydogdu, 2016a)
	Usefulness of technology	Positive	(Hite et al., 2002)
Psychological and behavioral factors	Attitudes and participation in water trading	Positive	(Aydogdu, 2016a)
	Satisfaction with water supply	Positive	(Knapp et al., 2018)
	Environmental risk awareness	Positive	(Azzi et al., 2018)
	Expectation about future irrigation	Positive	(Kassahun et al., 2016)
	Trust in service providers	Positive	(Saldías et al., 2016)
Environmental and crop protection innovations			
Sociodemographic data	Education	Positive	(Ayedun et al., 2017b)
	Age	Negative	(Chellappan and Sudha, 2015)
	Gender	Female (negative)	(Danso et al., 2017)
	Income	Positive	(Bogale, 2015)
	Family size and labor	Negative	(Ayedun et al., 2017a)
	Farming experience	Positive	(Danso et al., 2017)
Biophysical factors	Land and cultivated area	Positive	(Chellappan and Sudha, 2015)
	Yield/production	Positive	(Barrowclough and Alwang, 2018)
	Weather shocks	Positive	(Bogale, 2015)
Technological factors	Ease of use and usefulness	Positive	(Akter et al., 2017)
	Cost	Negative	(Cooper, 2003)
Psychological and behavioral factors	Environmental risk awareness	Positive	(Atreya, 2007)
	Risk aversion/perception	Negative	(Akter et al., 2017)
	Trust	Positive	(Akter et al., 2016)
Institutional factors	Credit and remittance	Positive	(Gulati and Rai, 2015)
	Incentives	Positive	(Villanueva et al., 2015)
	Information and source	Positive	(Khanal et al., 2018)
	Market access	Negative	(Gulati and Rai, 2015)
Crop and animal improvement technologies			
Sociodemographic data	Education	Positive	(Krishna and Qaim, 2007)
	Age	Inconclusive	(Schreiner and Latacz-Lohmann, 2015)
	Gender	Male (Positive)	(Narjes and Lippert, 2016)
	Income	Positive	(Narjes and Lippert, 2016)
	Family size and labor	Positive	(Asrat et al., 2010)
	Farming experience	Positive	(Asrat et al., 2010)
Biophysical factors	Land and cultivated area	Positive	(Krishna and Qaim, 2007)
	Adaptability of variety or breeds	Positive	(Asrat et al., 2010)
	Yield/production	Positive	(Asrat et al., 2010)

(continued)

Table 4. (continued)

Categories of determinants	Significant variables	Effect	References[a]
Technological factors	Production/consumption features	Positive	(Sánchez et al., 2017)
	Price of variety or tech	Negative	(Acheampong et al., 2018)
	Ease of use (previous experience)	Positive	(Marra et al., 2010)
	Usefulness	Positive	(Zander et al., 2009)
Psychological and behavioral factors	Attitude	Positive	(Chinedu et al., 2018)
	Risk awareness	Positive	(Hailu et al., 2017)
Institutional factors	Access to credit	Positive	(Matuschke et al., 2007)
	Information	Positive	(Asrat et al., 2010)

WTP: willingness to pay; WTA: willingness to accept.
[a]Many studies investigated the effect of the different determinants presented in Table 4. Only few of these references are shown in the table. The additional references are presented in Table S1 of the online supplementary file.

Table 5. Summary of number of studies, showing effect of significant factors on WTP (WTA) for different types of agricultural innovation by farmers.

	Water innovations		Environment related		Crop and animal improvement		Overall	
Determinants	(+)	(−)	(+)	(−)	(+)	(−)	(+)	(−)
Sociodemographic								
Education	6	2	10	3	4	1	20	6
Age	3	6	2	8	1	2	6	16
Gender (male)	1	3	4	3	—	—	5	6
Marital status	—	1	1	—	—	—	1	1
Income	8	1	11	1	2	0	21	2
Employment status	2	0	2	1	0	0	4	1
Household size	2	2	3	3	0	0	5	5
Farming experience	3	0	7	1	3	1	13	2
Property ownership	0	1	2	2	0	0	2	3
Dependency ratio	0	1	0	1	0	0	0	2
Biophysical factors								
Land owned	3	1	8	1	3	0	14	2
Cultivated area	5	2	6	0	0	0	11	2
Irrigated area	1	2	1	0	0	0	2	2
Yield/production	3	0	5	0	5	0	13	0
Environment shocks (e.g. water shortage and dry season)	6	0	5	0	0	0	11	0
Water source (groundwater)	6	2	N/A	N/A	N/A	N/A	6	2
Water quality (e.g. salinity)	8	0	N/A	N/A	N/A	N/A	8	0
Frequency of irrigation	2	0	N/A	N/A	N/A	N/A	2	0
Modern irrigation type	2	0	N/A	N/A	N/A	N/A	2	0
Technological factors								
Cost/price	0	13	0	9	0	10	0	32
Ease of use	0	0	2	0	0	0	2	0
Usefulness	0	0	2	0	3	0	5	0
Improvement	2	0	9	0	4	0	15	0
Adaptability (e.g. drought resistance)	0	0	5	0	2	0	7	0
Institutional factors								
Access to credit	1	0	4	0	1	0	6	0
Incentives	0	0	2	1	0	0	2	1
Information	0	0	5	1	4	0	9	1
Farmer association	1	0	1	1	1	0	3	1
Psychological factors								
Attitude (perception)	0	3	2	0	2	0	4	3
Risk awareness	3	0	8	0	2	0	13	0
Risk aversion	0	0	0	4	0	2	0	6
Trust/belief	2	0	0	2	3	0	5	2
Satisfaction	2	0	0	0	0	0	2	0
Knowledge and agricultural training	4	0	3	0	0	0	7	0

aware of the possible hypothetical bias that comes with asking the participants to bid for products that are not available at the bidding time. Future studies ought to be aware of these biases and how to minimize them. One way of reducing such biases is by applying cheap talk.

Considering the statistical approaches applied, a mixed logit model was commonly applied in studies that used CE in their WTP estimation, mainly because in CE, choices are based on the utility derived from attributes of a product or service (Kaczan and Swallow, 2013). However, studies often also apply the latent class model and random parameters logit model in CEs, because these methods relax the assumption of homogeneity in preferences (Asrat et al., 2010; Villanueva et al., 2015). The most common statistical model applied to CVM situation is the probit model, most likely because of its bivariate normal density function that allows for nonzero correlation, which is not possible with logistic regression (Bogale, 2015; Hill et al., 2013). In addition, it allows one to calculate the change in WTP brought by-product characteristics (Hill et al., 2013).

As noted by Prokopy et al. (2008), the results of any synthesis study are as good as the available data, which depend on the methods employed by the primary studies. As such, farmers' WTA/WTP and adoption studies have to consider the most relevant variables to include in the primary research. Some variables have been found to be consistently significant in determining farmers' WTP and have been presented in this review, providing a useful first step for the future studies.

Determinants of WTP (premium)

Our review has identified five groups of determinants of farmers' WTP/WTA. The role of each of them is discussed in the following subsections.

Sociodemographic factors. The decision to adopt or try an innovation in the traditional farming system requires knowledge and analytical capacity to understand such an innovation and the added values. As such, the level of education positively influenced WTP for agricultural innovation (Scaringelli et al., 2016). The positive effect of education on adoption has been reported in a number of existing studies, including in review studies (Marr et al., 2016; Tey and Brindal, 2012). In our review, younger farmers have been shown to be willing to pay more for innovative technologies, not only because they tend to be less conservative than the older farmers (Chellappan and Sudha, 2015) but also because they expect to enjoy the benefits over a longer period (Larue et al., 2014). In the instances where age had a positive effect, it is thought to be related to the farming experience (also a positive significant determinant). The positive effect of income on farmers' WTP for agricultural innovations compares well with results from consumer WTP studies on novel foods (Lusk and Hudson, 2004). For environmental innovations, such as PES, high-income farmers may be willing to pay more because they have more flexibility to invest in future sustainable farming systems (Gulati and Rai, 2015). Family size is related to the amount of labor for farmwork as well as to the diversity of sources of family income, which could explain its positive effect on WTP. In the instances where family size had a negative effect on WTP for agricultural innovations, it can be argued that bigger families have more chances to engage in nonfarm activities, limiting them to pay higher premium. Furthermore, the effect of gender on WTP/WTA reflects a disparity in preferences for agricultural innovations that are affected by access to credit, information, and financial literacy, especially in developing nations. Female farmers are for example constrained by cultural norms and lack of resources (Patel, 2012), which could affect their food production and preferences for certain innovations.

It is worth noting that while sociodemographic variables are still very important determinants of farmers' WTP/WTA in developing countries, this review showed that for many studies conducted in developed and high-income countries, sociodemographic variables such as education, household size, and income levels were not often included as potentially important variables, and when considered, oftentimes did not have significant effect on adoption or WTP (Giannoccaro et al., 2015; Tur-Cardona et al., 2018; Villanueva et al., 2015). Demographic factors, such as family size, do not vary a lot within developed countries, which could explain why these factors are not significant in studies carried out in such regions. It also appears to provide a basis to exclude some of these variables from the studies or models, depending on the design and nature of each study.

Biophysical factors. The amount of farmland owned is a proxy for the economy of scale and, as also stated by Tey and Brindal (2012), larger farms have a greater capacity to absorb costs and risks associated with new technologies or innovations. Indeed in our review, farm size and irrigated and cropped area have been found to have positive effect on farmers' WTP for agri-innovations. Environmental adaptability of improved variety had a positive effect. This is particularly important in the face of climate change that is predicted to adversely affect food production in certain climatic areas and the realization of SDG 2 (Mugambiwa and Tirivangasi, 2017). In the case of environmental and crop protection innovations, previous weather shocks (e.g. moisture stress) are found to motivate farmers to pay more for environmental protection. For instance, faced with climate change impacts, farmers in Nigeria have embraced and preferred drought-tolerant maize (Tambo and Abdoulaye, 2012). This aspect shows that farmers value the environmental impacts of agricultural innovations and would be willing to pay more for those innovations that are adaptable to environmental change.

Technological factors. As expected, the cost of an innovation negatively affected WTP, with most farmers willing to pay values less than the cost of the technology. However, the cost and WTP relationship is likely to depend on the type of innovation and its attributes. For instance, the effect of cost on WTP will likely depend on whether incentives to implement an agricultural innovation are given to farmers or not, especially where the farmers cannot afford the innovations. In Mozambique, farmers recently stated that incentives such as agro inputs, nutrition training, and market support would motivate them to adopt and grow vitamin A biofortified sweet potatoes (Jenkins et al., 2018). The other widely studied technological factors include the ease of use and usefulness of the agricultural innovations, which were found to be significant and positive in determining WTP/WTA. These aspects of innovations have been extensively examined using the technology acceptance model (TAM) and its extended version TAM2 (Mogendi et al., 2016; Venkatesh and Davis, 2000) and the results of these studies confirm their positive effect on adoption of innovations. Once farmers know how to implement a particular technology, their WTP (adoption possibility) increases, which might call for training in the case of less known innovations.

Institutional factors. The roles that institutions such as financial, private, and government agencies can play in enhancing the uptake of agricultural innovation are vast. Access to information positively influences the uptake of innovations as it enables acquisition of advice and technical support needed by farmers. In fact, it has been emphasized that farmers will only accept technologies they are aware of or those they have heard about (Mwangi and Kariuki, 2015). However, the quality (and source) of information also have influence on WTP and adoption (Kabunga et al., 2012). Where information is not properly packaged, farmers could incorrectly evaluate certain innovations, which could lead to low adoption (Kabunga et al., 2012; Mwangi and Kariuki, 2015). This implies that the information has to be accurate, reliable, and consistent as adoption is more likely when the information and the innovation are seen as useful. The other institutional factors, access to credit, incentives, and belonging to a farmer group or association, have the expected positive effects on WTA/WTP by farmers. These are modifiable factors, so agencies and governments should take advantage of these to promote adoption of agricultural innovations by farmers. For instance, governments can improve access to soft loans for poor farmers to take up new farming practices.

Psychological and behavioral factors. Herath (2010) emphasized that the acceptance of new technologies are dependent on stakeholders' (e.g. farmers) behavioral change, which are determined by their norms, beliefs, and attitudes. Only few articles have studied farmers' psychological factors that could inform their preference for agricultural innovations. Risk aversion, risk awareness, and perceptions, for instance, have been found to significantly influence WTP by farmers (Hill et al., 2013; McIntosh et al., 2013). This review adds to the growing concerns to include psychological factors into the adoption models. The study of Tambo and Abdoulaye (2012) attests to this call as they found positive effect of the farmers' perceptional factors on adoption of drought-resistant maize. In another study, it has been emphasized that farmers' aspirations are important in making adoption decision (Mausch et al., 2018), further pointing to the importance of cognitively linked (psychological) factors in adoption. The need to integrate psychological factors in adoption studies has also been emphasized in the reviews of Tey and Brindal (2012) and Meijer et al. (2015), which analyzed effect of perception, knowledge, and attitude on the uptake of innovations.

Summary and conclusions

Agricultural innovations are important for sustainable production of food to reduce global hunger and food insecurity, as clearly spelt in SDG 2. This review provides a comprehensive overview of studies on farmers' WTP for innovative agricultural practices or technologies as a proxy for their adoption. Farmers are generally willing to pay for the innovations but the values and determinants highly depend on the specific innovations studied. Despite inconclusiveness of literature on determinants of innovation uptake by farmers, a number of consistent factors have been identified through this review. While education, farming experience, income, farm size, land, access to credit, information, and yield are consistently found to be positive determinants across the studies reviewed, age and cost of innovations are consistently negative determinants of farmers' WTP/WTA.

Sociodemographic and farm-related factors have more often been studied compared to behavioral and other intrinsic determinants (such as perceptions, attitudes, and knowledge) of farmers' adoption and WTP/WTA. This makes it hard to fully understand the reaction of farmers to agricultural innovations and could partly explain why literature has not been conclusive on the determinants of adoption. Comprehensive studies integrating psychological factors into the commonly studied sociodemographic and farm characteristics would yield better understanding of farmer adoption and WTP.

From a policy angle, the review reveals the need to train farmers in particular innovation aspects, in line with the effect of access to information, a positive significant determinant of WTP. The rationale is that when farmers have the information on the benefits and application of innovations (ease of use and usefulness), they are more likely to adopt them. Modifiable factors such as access to information, market, and credit are easy to tackle to improve adoption. Other nonmodifiable factors such as age should be used to consider the type of farmers to target with certain innovations for better results.

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Supplemental material

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References

Adenle AA, Azadi H and Manning L (2018) The era of sustainable agricultural development in Africa: understanding the benefits and constraints. *Food Reviews International* 34(5): 411–433.

Andersson JA and D'Souza S (2014) From adoption claims to understanding farmers and contexts: a literature review of Conservation Agriculture (CA) adoption among smallholder farmers in southern Africa. *Agriculture, Ecosystems & Environment* 187: 116–132.

Asrat S, Yesuf M, Carlsson F, et al. (2010) Farmers' preferences for crop variety traits: lessons for on-farm conservation and technology adoption. *Ecological Economics* 69(12): 2394–2401.

Aubert BA, Schroeder A and Grimaudo J (2012) IT as enabler of sustainable farming: an empirical analysis of farmers' adoption decision of precision agriculture technology. *Decision Support Systems* 54(1): 510–520.

Baumgart-Getz A, Prokopy LS and Floress K (2012) Why farmers adopt best management practice in the United States: a meta-analysis of the adoption literature. *Journal of Environmental Management* 96(1): 17–25.

Bigliardi B and Galati F (2013) Innovation trends in the food industry: the case of functional foods. *Trends in Food Science & Technology* 31(2): 118–129.

Bogale A (2015) Weather-indexed insurance: an elusive or achievable adaptation strategy to climate variability and change for smallholder farmers in Ethiopia. *Climate and Development* 7(3): 246–256.

Bozorg-Haddad O, Malmir M, Mohammad-Azari S, et al. (2016) Estimation of farmers' willingness to pay for water in the agricultural sector. *Agricultural Water Management* 177: 284–290.

Buckley C, Hynes S and Mechan S (2012) Supply of an ecosystem service—farmers' willingness to adopt riparian buffer zones in agricultural catchments. *Environmental Science & Policy* 24: 101–109.

Carletto G, Ruel M, Winters P, et al. (2015) Farm-level pathways to improved nutritional status: introduction to the special issue. *The Journal of Development Studies* 51(8): 945–957.

Chellappan S and Sudha R (2015) Investment, adoption, attitude and extent of participation of farmers in soil conservation projects in the Western Ghats of India: revised topic. *International Journal of Social Economics* 42(3): 251–275.

Collier P and Dercon S (2014) African agriculture in 50 years: smallholders in a rapidly changing world? *World Development* 63: 92–101.

De Steur H, Wesana J, Blancquaert D, et al. (2016) Methods matter: a meta-regression on the determinants of willingness-to-pay studies on biofortified foods. *Annals of the New York Academy of Sciences* 1390(1): 34–46.

Douthwaite B, Keatinge J and Park J (2001) Why promising technologies fail: the neglected role of user innovation during adoption. *Research Policy* 30(5): 819–836.

Feder G and Umali DL (1993) The adoption of agricultural innovations: a review. *Technological Forecasting and Social Change* 43(3-4): 215–239.

Giannoccaro G, Castillo M and Berbel J (2015) An assessment of farmers' willingness to participate in water trading in southern Spain. *Water Policy* 17(3): 520–537.

Giupponi C and Gain AK (2017) Integrated spatial assessment of the water, energy and food dimensions of the sustainable development goals. *Regional Environmental Change* 17(7): 1881–1893.

Glover D, Sumberg J and Andersson JA (2016) The adoption problem; or why we still understand so little about technological change in African agriculture. *Outlook on Agriculture* 45(1): 3–6.

Gulati A and Rai SC (2015) Farmers' willingness-to-pay towards soil and water conservation measures in agro-ecosystems of Chotanagpur Plateau, India. *Water and Environment Journal* 29(4): 523–532.

Herath CS (2010) Motivation as a potential variable to explain farmers' behavioral change in agricultural technology adoption decisions. *E+M Ekonomie a Management* 13(3): 62–70.

Hill RV, Hoddinott J and Kumar N (2013) Adoption of weather-index insurance: learning from willingness to pay among a panel of households in rural Ethiopia. *Agricultural Economics* 44(4-5): 385–398.

Jenkins M, Shanks CB, Brouwer R, et al. (2018) Factors affecting farmers' willingness and ability to adopt and retain vitamin A-rich varieties of orange-fleshed sweet potato in Mozambique. *Food Security* 10(6): 1501–1519.

Kabunga NS, Dubois T and Qaim M (2012) Heterogeneous information exposure and technology adoption: the case of tissue culture bananas in Kenya. *Agricultural Economics* 43(5): 473–486.

Kaczan D and Swallow BM (2013) Designing a payments for ecosystem services (PES) program to reduce deforestation in Tanzania: an assessment of payment approaches. *Ecological Economics* 95: 20–30.

Kamrath C, Wesana J, Bröring S, et al. (2019) What do we know about chain actors' evaluation of new food technologies? A systematic review of consumer and farmer studies. *Comprehensive Reviews in Food Science and Food Safety* 18(3): 798–816.

Khan ZR, Midega CA, Pittchar JO, et al. (2014) Achieving food security for one million sub-Saharan African poor through push–pull innovation by 2020. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 369(1639): 20120284.

Knowler D and Bradshaw B (2007) Farmers' adoption of conservation agriculture: a review and synthesis of recent research. *Food Policy* 32(1): 25–48.

Krishna VV and Qaim M (2007) Estimating the adoption of Bt eggplant in India: who benefits from public–private partnership? *Food Policy* 32(5): 523–543.

Larue B, West GE, Tamini LD, et al. (2014) Willingness to pay for BMP-induced water quality benefits and deviations around expected water quality outcomes. *Canadian Water Resources Journal/Revue Canadienne des Ressources Hydriques* 39(4): 437–448.

Lewis JJ and Pattanayak SK (2012) Who adopts improved fuels and cookstoves? A systematic review. *Environmental Health Perspectives* 120(5): 637.

Lusk JL and Hudson D (2004) Willingness-to-pay estimates and their relevance to agribusiness decision making. *Review of Agricultural Economics* 26(2): 152–169.

Marr A, Winkel A, van Asseldonk M, et al. (2016) Adoption and impact of index-insurance and credit for smallholder farmers in developing countries: a systematic review. *Agricultural Finance Review* 76(1): 94–118.

Matuschke I, Mishra RR and Qaim M (2007) Adoption and impact of hybrid wheat in India. *World Development* 35(8): 1422–1435.

Mausch K, Harris D, Heather E, et al. (2018) Households' aspirations for rural development through agriculture. *Outlook on Agriculture* 47(2): 108–115.

McIntosh C, Sarris A and Papadopoulos F (2013) Productivity, credit, risk, and the demand for weather index insurance in smallholder agriculture in Ethiopia. *Agricultural Economics* 44(4-5): 399–417.

Meijer SS, Catacutan D, Ajayi OC, et al. (2015) The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. *International Journal of Agricultural Sustainability* 13(1): 40–54.

Mercer DE (2004) Adoption of agroforestry innovations in the tropics: a review. *Agroforestry Systems* 61(1): 311–328.

Mogendi JB, De Steur H, Gellynck X, et al. (2016) A novel framework for analysing stakeholder interest in healthy foods: a case study on iodine biofortification. *Ecology of Food and Nutrition* 55(2): 182–208.

Mugambiwa SS and Tirivangasi HM (2017) Climate change: a threat towards achieving' Sustainable Development Goal number two'(end hunger, achieve food security and improved nutrition and promote sustainable agriculture) in South Africa. *Jàmbá: Journal of Disaster Risk Studies* 9(1): 1–6.

Mwangi M and Kariuki S (2015) Factors determining adoption of new agricultural technology by smallholder farmers in developing countries. *Journal of Economics and Sustainable Development* 6(5): 208–216.

Or CK and Karsh B-T (2009) A systematic review of patient acceptance of consumer health information technology. *Journal of the American Medical Informatics Association* 16(4): 550–560.

Osborne A, Blake C, Fullen BM, et al. (2012) Prevalence of musculoskeletal disorders among farmers: a systematic review. *American Journal of Industrial Medicine* 55(2): 143–158.

Pandey VL, Dev SM and Jayachandran U (2016) Impact of agricultural interventions on the nutritional status in South Asia: a review. *Food Policy* 62: 28–40.

Pannell DJ, Llewellyn RS and Corbeels M (2014) The farm-level economics of conservation agriculture for resource-poor farmers. *Agriculture, Ecosystems & Environment* 187: 52–64.

Pannell DJ, Marshall GR, Barr N, et al. (2006) Understanding and promoting adoption of conservation practices by rural landholders. *Australian Journal of Experimental Agriculture* 46(11): 1407–1424.

Patel RC (2012) Food sovereignty: power, gender, and the right to food. *PLOS Medicine 9*(6):e1001223.

Peek ST, Wouters EJ, van Hoof J, et al. (2014) Factors influencing acceptance of technology for aging in place: a systematic review. *International Journal of Medical Informatics* 83(4): 235–248.

Prokopy LS, Floress K, Klotthor-Weinkauf D, et al. (2008) Determinants of agricultural best management practice adoption: evidence from the literature. *Journal of Soil and Water Conservation* 63(5): 300–311.

Qaim M and De Janvry A (2003) Genetically modified crops, corporate pricing strategies, and farmers' adoption: the case of Bt cotton in Argentina. *American Journal of Agricultural Economics* 85(4): 814–828.

Rogers EM (1995) Attributes of innovations and their rate of adoption. In: Rogers EM (ed) *Diffusion of Innovations*. New York: The Free Press, pp. 204–251.

Rosenstock TS, Lamanna C, Chesterman S, et al. (2016) *The scientific basis of climate-smart agriculture: a systematic review protocol*. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Saldías C, Speelman S, Van Huylenbroeck G, et al. (2016) Understanding farmers' preferences for wastewater reuse frameworks in agricultural irrigation: lessons from a choice experiment in the Western Cape, South Africa. *Water SA* 42(1): 26–37.

Scaringelli MA, Giannoccaro G, Prosperi M, et al. (2016) Adoption of biodegradable mulching films in agriculture: is there a negative prejudice towards materials derived from organic wastes? *Italian Journal of Agronomy* 11(2): 92–99.

Siddique KH, Johansen C, Turner NC, et al. (2012) Innovations in agronomy for food legumes. A review. *Agronomy for Sustainable Development* 32(1): 45–64.

Stafford-Smith M, Griggs D, Gaffney O, et al. (2017) Integration: the key to implementing the sustainable development goals. *Sustainability Science* 12(6): 911–919.

Tambo JA and Abdoulaye T (2012) Climate change and agricultural technology adoption: the case of drought tolerant maize in rural Nigeria. *Mitigation and Adaptation Strategies for Global Change* 17(3): 277–292.

Tey YS and Brindal M (2012) Factors influencing the adoption of precision agricultural technologies: a review for policy implications. *Precision Agriculture* 13(6): 713–730.

Tur-Cardona J, Bonnichsen O, Speelman S, et al. (2018) Farmers' reasons to accept bio-based fertilizers: a choice experiment in seven different European countries. *Journal of Cleaner Production* 197: 406–416.

Venkatesh V and Davis FD (2000) A theoretical extension of the technology acceptance model: four longitudinal field studies. *Management Science* 46(2): 186–204.

Villanueva AJ, Gómez-Limón JA, Arriaza M, et al. (2015) The design of agri-environmental schemes: farmers' preferences in southern Spain. *Land Use Policy* 46: 142–154.

Welch RM and Graham RD (2005) Agriculture: the real nexus for enhancing bioavailable micronutrients in food crops. *Journal of Trace Elements in Medicine and Biology* 18(4): 299–307.

Wong WC, Cheung CS and Hart GJ (2008) Development of a quality assessment tool for systematic reviews of observational studies (QATSO) of HIV prevalence in men having sex with men and associated risk behaviours. *Emerging Themes in Epidemiology* 5(1): 23.