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Is precision viticulture worth the effort? An evaluation using the Price Sensitivity Meter and experimental auctions

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Abstract

This study examines consumers' willingness to pay (WTP) for "precision viticulture" in the production of the Italian wine "Falanghina del Sannio" using van Westendorp's Price Sensitivity Meter (PSM) and Becker-deGroot-Marschak (BDM) experimental auctions. Results show that the "precision viticulture" attribute contributes approximately 22.25% to the total value of a sustainable bottle, with revenues maximised at the price of 2 Euros. A 1% price increase reduces demand by 3.31%. Higher baseline wine values and female consumers show higher WTP. These insights can guide policymakers and wine producers in pricing and marketing sustainable wine, especially to environmentally-conscious and high-value consumers, particularly women.

Keywords

Becker-deGroot-Marschak experimental auction – Falanghina del Sannio – precision viticulture – van Westendorp's price sensitivity meter – Italian wine

1 Introduction

The sustainability of food systems is a cornerstone of contemporary economic, social, and environmental debates, with Europe aiming to achieve climate neutrality by 2050. This vision extends to agriculture, prioritizing sustainability, innovation, and technology (EC, 2017). The Common Agricultural Policy (CAP) supports these goals by fostering a resilient agricultural sector, advancing environmental protection, and stimulating rural economic growth (Nazzaro *et al.*, 2022). In recent years, sustainability has increasingly influenced consumers' behaviour. Consumers are showing greater interest in environmental and social issues, which has led to new consumption demands, including intangible needs (Smeding *et al.*, 2023; Yang *et al.*, 2023; Britwum *et al.*, 2021). As a result, companies are adopting socially responsible practices, meeting these evolving needs by introducing sustainable innovations that generate positive environmental and social externalities (Iakovou *et al.*, 2014; Marotta, Nazzaro, 2012, 2020; Apicella and Tarabella, 2024).

The wine sector, a major contributor to greenhouse gas (GHG) emissions (Recchia *et al.*, 2018; Sarri *et al.*, 2020) and a key player in the Italian and European agrifood systems (Nazzaro *et al.*, 2022; Pomarici and Sardone, 2020), is increasingly adopting sustainable production processes driven by smart and green innovations

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(Fiore *et al.*, 2017; Dries *et al.*, 2013). Some wineries are shifting their investment priorities toward precision and smart agriculture (Giuliani *et al.*, 2011), utilising information and communication technologies such as Big Data Analytics to explore data variability and adapt to changes in the agricultural sector (Lasso and Corrales, 2018). These technologies are commonly used to monitor and control factors like temperature, water, and soil nutrients (Shafi *et al.*, 2019) as well as to optimise production variables (e.g., herbicides and fertilisers use) to ensure the efficient use of human and environmental resources (Bhakta *et al.*, 2019; Giraldo *et al.*, 2017).

Extensive literature highlights the positive effect of information concerning sustainable production processes on consumer preferences and willingness to pay (WTP) (Lanfranchi *et al.*, 2019; Stanco and Lerro, 2020; Vecchio *et al.*, 2023). More specifically, studies targeting European and US consumers have found a higher WTP for sustainable wines (Sogari *et al.*, 2016; Pomarici *et al.*, 2016). However, many of these studies focus solely on hypothetical scenarios, raising questions about how consumer behaviour translates into real-world decisions.

This study aims to investigate how consumers perceive the value of sustainable innovation in the wine sector by combining hypothetical and real scenarios. Consumers were asked about their WTP to upgrade a regular bottle of Italian wine, "Falanghina del Sannio", to an equivalent bottle from the same winemaker, with the same brand, grape variety, cultivated in the same geographical area, but produced using a "precision viticulture" system in the vineyard. The regular wine's value was estimated using van Westendorp's *hypothetical* Price Sensitivity Meter (PSM) (1976). The value of the "precision viticulture" attribute was measured through experimental auctions using the BDM mechanism (Becker *et al.*, 1964), which enabled the estimation of its demand curve and the price to maximise revenues. The price elasticity of the new wine bottle, as a composite of the regular wine's value and the "precision viticulture" attribute, was then calculated. Finally, the relationship between the "precision viticulture" attribute and the value of the regular wine bottle was analysed econometrically.

The paper is structured as follows: Section 2 describes the data and methods used, Section 3 presents the results and discussion, and Section 4 illustrates the conclusions.

2 Materials and Methods

A behavioural experiment was conducted from June 2023 to December 2023. The experiment had two phases. First, participants completed an online questionnaire, administered via email, to provide their socio-demographic profiles. They were then invited to the Food, Agriculture, and Resource Economics Laboratory (FARE-Lab, https://site.unibo.it/fare-lab/it) of the University of Bologna to complete a second questionnaire that included two experimental tasks. In the first task, participants evaluated a regular bottle of wine using the van Westendorp's PSM. In the second task, they participated in an experimental auction with endowment, using the BDM mechanism to assess their WTP for exchanging the regular bottle of wine with a new one produced using "precision viticulture". This experimental auction allowed for the evaluation of the "precision viticulture" attribute, *ceteris paribus*.

2.1 *Van Westendorp' Price Sensitivity Meter*

The van Westendorp Price Sensitivity Meter (PSM) is a method used to determine the price range for a product, typically a new one (Paczowski, 2018). The method has two key characteristics (Kloss and Kunter, 2016): first, it is *direct*, as participants are asked four pricing-related questions about a specific product; second, it is *hypothetical*, meaning participants are not required to purchase the product. Due to its ease of implementation, van Westendorp's PSM is widely used in market pricing scenarios. Examples of its application in academic research include studies on 4G services (Khandker and Joshi, 2019), algae-based meat substitutes (Weinrich and Gassler, 2021), and trophy hunting (Moorhouse *et al.*, 2023). This study applied van Westendorp's PSM to evaluate the price range for a regular bottle of "Falanghina del Sannio" wine. The following four questions were posed to participants:

1. *Too cheap*: At what price would the regular bottle of wine become so cheap that you would question its quality and refrain from purchasing it?
2. *Cheap*: At what price would you consider the regular bottle of wine cheap but still a good deal?
3. *Expensive*: At what price would you consider the regular bottle of wine expensive, but still worth buying?
4. *Too expensive*: At what price would the regular bottle of wine be too expensive to purchase?

As suggested by Paczkowski (2018), the logical consistency of responses is checked against the rule: "too cheap" ≤ "cheap" ≤ "expensive" ≤ "too expensive". Participants with inconsistent responses are excluded from the dataset. This procedure enables the calculation of cumulative frequency distributions for each of the four price categories. These distributions are then used to identify four key points based on their pairwise intersections:

1. Optimal Price Point (OPP): the point where the percentage of individuals rating the wine "too cheap" equals the percentage rating it as "too expensive". This is interpreted as the equilibrium price in van Westendorp's analysis (Wilczyński and Johnston, 2023);
2. Indifference Price Point (IPP): the point where the percentage of individuals rating the wine as "cheap" equals the percentage rating it as "expensive";
3. Point of Marginal Cheapness (PMC): the point where the percentage rating the wine as "too cheap" equals the percentage rating it as "expensive";
4. Point of Marginal Expensiveness (PME): the point where the percentage rating the wine as "cheap" equals the percentage rating it as "too expensive".

It is important to note that the interval between PMC-PME defines the suggested price range of the regular bottle of wine.

2.2 *Becker-DeGroot-Marschak experimental auction*

The Becker-DeGroot-Marschak (BDM) auction mechanism is characterized by two key features: first, each participant competes against a computer rather than other participants to acquire a specific product; second, if a participant places a bid higher than the price randomly drawn by the computer, they win the product and pay the computer's price. This ensures that what is offered is independent of what is paid. BDM auctions are designed to be incentive-compatible, meaning participants are encouraged to bid their true value for the product (Lusk *et al.*, 2004). The experiment is conducted within-subject, meaning all participants experience the same experimental conditions. The auction uses the *endowment* mechanism; each participant is given a regular bottle of wine as an endowment before the auction begins. They are then asked how much they would pay to exchange the regular bottle for an upgraded version produced using "precision viticulture". The two products are identical in all aspects (brand, grape variety, alcohol content, production area) except for the "precision viticulture" attribute. At the end of the auction, if a participant bid exceeds the randomly drawn price, they receive the upgraded bottle of wine and pay the computer's price. Otherwise, they keep the regular bottle. This exchange process is essential for evaluating the precision viticulture attribute. The experimental auction setting aims to prevent playful or competitive behavior by requiring participants to make a real monetary commitment. This ensures that participants are motivated to provide accurate valuations rather than bidding for the sake of winning. A mismatch between a participant's true evaluation and their bid would result in paying real money for a product they do not value, discouraging frivolous bidding behavior.

2.3 *From theory to practice: the procedure*

The detailed procedure used for the experiment is described as follows:

- Participants were recruited via distribution of flyers, posters and email invitations;
- Participants answered the socio-demographic survey provided via email. They were then invited to book a slot for the laboratory experiment according to their time preferences;
- Upon entering the laboratory, each participant is informed by the experimenter about the characteristics and purposes of the experiment;
- The participant is given a regular bottle of wine as an *endowment*;
- Each participant evaluates the regular bottle of wine, answering the four questions the van Westendorp's PSM framework requires;
- The participant then evaluates the attribute "precision viticulture" through the BDM experimental auction;
- Once the experiment ends, the participant is invited to leave the laboratory with a voucher of 15.00 Euros and a bottle of wine – regular or upgraded.

2.4 *Data collection and sample description*

Participants were recruited using two channels. Some were selected from the pool of individuals who regularly shop at the University of Bologna's experimental farm (AUB–UniBo), which sells local agricultural products such as fruits, vegetables, jams and wines. Others were recruited in person by sponsoring the event and distributing flyers in recreational areas, such as shops and markets. Each participant was offered a €15.00 voucher to spend on any product of the AUB–UniBo to encourage participation. All auctions were conducted in a laboratory environment rather than in the field to ensure maximum control over the experiment.

This process resulted in an initial sample of 168 participants. After excluding responses with logical inconsistencies (Paczowski, 2018) in van Westendorp's analysis, the final sample consisted of 159 individuals. Although the sample size is relatively small, it is consistent with similar studies using experimental auctions (Ran *et al.*, 2017; Raimondo *et al.*, 2024). The core socio-demographic characteristics of the sample are presented in Table 1.

After the experiment, the data were statistically analysed to determine the impact of the "precision viticulture" attribute on the value of the regular product.

TABLE 1 Sample characteristics

Variables	N	Frequency (%)
Gender		
Male	58	36.48
Female	101	63.52
Age group (years)		
18–24	22	13.84
25–34	23	14.47
35–44	21	13.21
45–54	46	28.93
55–64	35	22.01
65	12	7.55
Educational level		
Middle school	3	1.89
High school	44	27.67
University (*bachelor or master*)	54	33.96
Post-graduate (*e.g., PhD, specialisation*)	58	36.48
Occupational status		
Unemployed	1	0.63
Student	31	19.50
Paid worker	110	69.18
Self-employed worker	6	3.77
Retired	11	6.92
Perceived economic status		
Low (*economic difficulties*)	9	5.66
Middle	107	67.30
High (*no economic difficulties*)	43	27.04

SOURCE: AUTHORS' CALCULATIONS

Additionally, characteristics influencing significant variation in the WTP for the "precision viticulture" attribute were analysed using Ordinary Least Squares (OLS). The online questionnaire and laboratory experiment were conducted using the software Qualtrics (https://www.qualtrics.com). Statistical analysis was performed using Julia 1.10.0 (Bezanson, 2017) and STATA 17 (https://www.stata.com).

3 Results and Discussion

The study examined the WTP for upgrading a bottle of Italian wine to one produced using a precision farming system. The analysis focused on wines that were identical in terms of winemaker, brand, grape variety, and geographic origin. This WTP represents the additional value of the "precision viticulture" attribute compared to a standard bottle of wine. To determine the hypothetical value of a bottle of wine produced through "precision viticulture" the study considered two components: the value of a standard bottle, estimated using van Westendorp's PSM, and the value of the "precision viticulture" attribute, determined through the BDM experimental auction mechanism.

3.1 *Descriptive statistics of price variables*

Table 2 provides some descriptive statistics (i.e. mean, median, minimum value, maximum value and standard deviation) of the price variables used throughout the article. These are the WTP for the attribute "precision viticulture" and the answers to questions "Too cheap", "Cheap", "Expensive", and "Too expensive" relative to van Westendorp's analysis.

TABLE 2 Descriptive statistics (values in Euro; N = 159)

	Mean	Median	Min	Max	Std. Dev.
WTP	2.71	1.75	0	30	3.73
Too cheap	4.21	4	1	15	2.11
Cheap	6.75	6	2	18	2.79
Expensive	9.67	8.5	3.5	25	3.85
Too expensive	12.35	10	5	30	4.86

SOURCE: AUTHORS' CALCULATIONS

As shown in Table 2, the mean and median values of the regular bottle of wine originated by Van Westendorp's analysis are logically consistent and larger than the WTP for the attribute "precision viticulture" measured through the BDM experimental auction.

The variability – expressed in terms of standard deviation – of the answers concerning the valuation of the regular wine follows the rule "too cheap" < "cheap" < "expensive" < "too expensive", thus denoting an increasing indecision in defining when a wine becomes too expensive. Regarding variability, the attribute "precision viticulture" positions itself between cheap and expensive.

3.2 *Van Westendorp analysis of regular wine bottle*

A graphical representation of van Westendorp's analysis is shown in Figure 1, illustrating the cumulative percentage of respondents in relation to the bottle's price (in

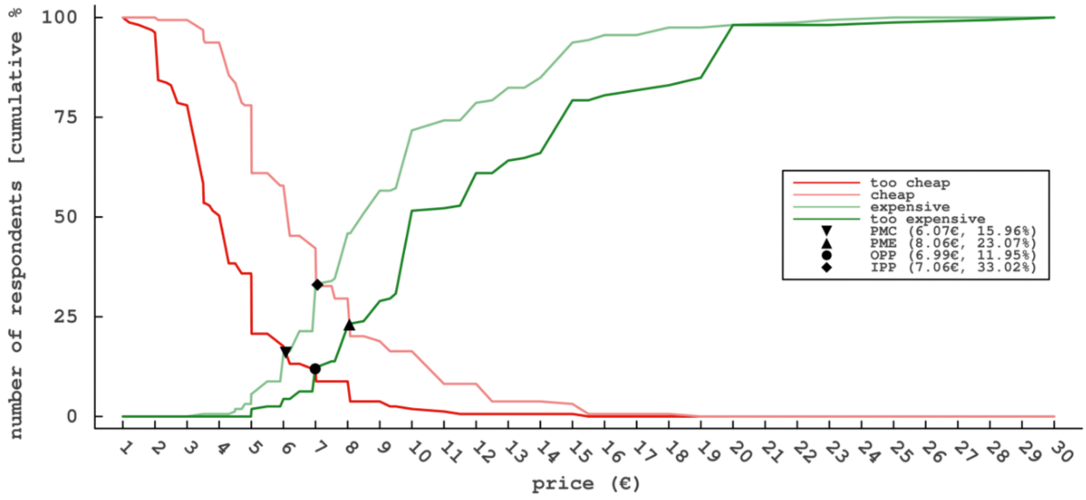

FIGURE 1 van Westendorp's Price Sensitivity Meter for the regular bottle of wine

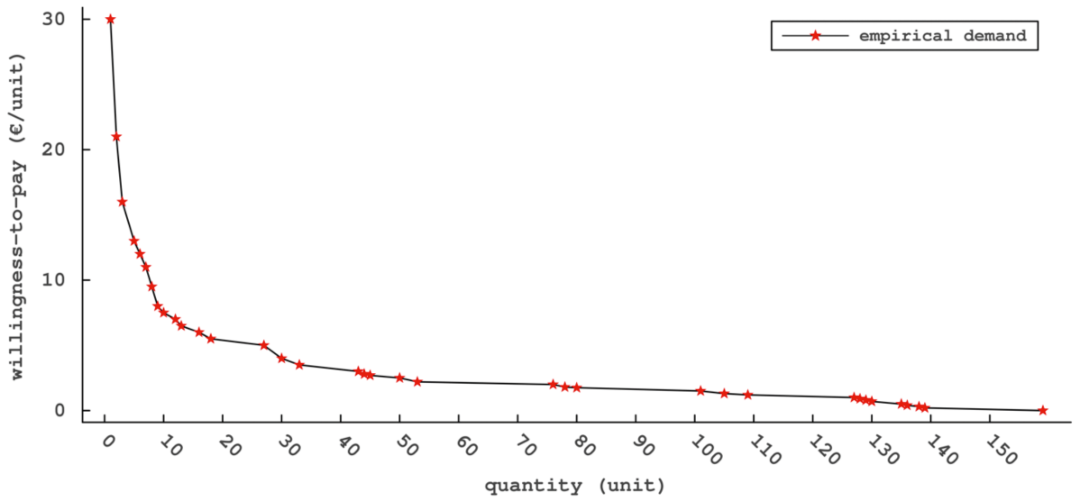

FIGURE 2 Empirical demand curve for "precision viticulture"

Euros). The red and light red lines represent the cumulative frequencies of "too cheap" and "cheap" responses, while the green line and the light green line correspond to "too expensive" and "expensive" responses, respectively.

The findings indicate that the appropriate price range for a regular bottle of wine should be between 6.07 Euros (15.96%) to 8.06 Euros (23.07%). The optimal PSM price is determined to be 6.99 Euros, as only 11.95% of respondents consider it either "too cheap" or "too expensive".

3.3 *Empirical demand and revenue analysis for the attribute*

The empirical demand curve for bids to exchange the regular bottle of wine with one from "precision agriculture" is illustrated in Figure 2, with red stars representing quantity and WTP pairs. The empirical demand curve exhibits a negative and downward-sloping trend.

Figure 3 displays the WTP value that maximises potential revenue for the "precision viticulture" attribute. A discrete maximisation algorithm was used to determine this price, calculated to be 2.0 Euros for this sample.

Considering the new bottle of wine as a combination of the regular bottle and the "precision viticulture attribute", the resulting revenue maximizing price contributes approximately 22.25% to the total value of the upgraded bottle. Overall, the "precision viticulture" attribute accounts for between 19.88% and 24.78% of the total value of the upgraded bottle.

3.4 *Combining van Westendorp's PSM and BDM: the own-price demand elasticity of the new bottle of wine*

To determine the elasticity of demand for a hypothetical bottle of wine produced using precision viticulture, we

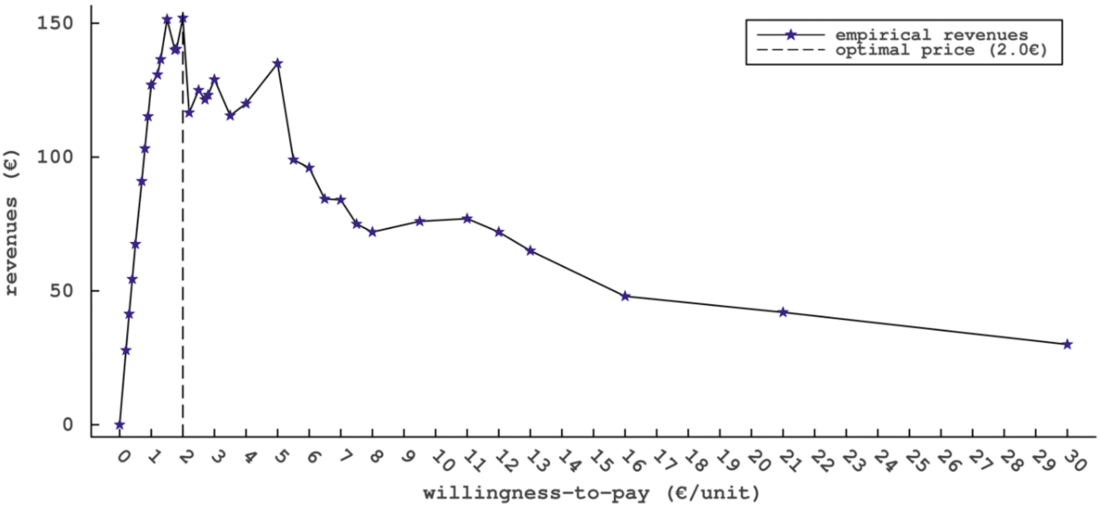

FIGURE 3 Empirical revenue for "precision viticulture"

combine the regular bottle of wine with the "precision viticulture" attribute. This is done using a log-log model (natural logarithm) as shown in Equation 1:

$$\ln(Q_{sw}) = \gamma + \beta \ln(P_{sw}) + \varepsilon \quad (1)$$

Where Q_{sw} is the quantity demanded for the new bottle of wine, and P_{sw} is the unit price of the bottle. The unit price is calculated by adding the optimal PSM price of the regular bottle of wine from van Westendorp's PSM analysis (6.99 Euros) to the values assigned to the "precision agriculture" attribute in the experimental auctions. This approach allows us to calculate the constant elasticity without disregarding information from 0 bids, which could have posed challenges in computing natural logarithms. The parameters α and β are estimated using 36 observations (36 unique prices for 36 quantities) out of 159, after reducing duplicate prices to unique values. The OLS estimation of Equation 1 yields estimates $\hat{\gamma} = 11.47$ and $\hat{\beta} = -3.31$, both significantly different from 0 at the 1% level. The R^2 value of 0.98 indicates a high goodness-of-fit. The negative sign of $\hat{\beta}$ is coherent with price elasticity, thus denoting a downward-sloping behaviour. Specifically, a 1% increase in the price of the new wine from "precision viticulture" results in a 3.31% decrease in the quantity demanded.

3.5 *Combining van Westendorp's PSM and BDM: relationship between "precision viticulture" and the value of regular wine*

The relationship between the WTP to exchange the regular bottle for the new one, specifically, the WTP for the "precision viticulture" attribute, and the value of the regular bottle is expressed by Equation 2:

$$WTP = \alpha + \beta P_{bottle} + controls + \varepsilon \quad (2)$$

In this equation, *WTP* represents the willingness to pay for the attribute "precision viticulture", while P_{bottle} serves as a proxy for the value of the regular bottle derived from van Westendorp's PSM analysis. P_{bottle} is calculated by averaging the variables "too cheap" and "too expensive" for each individual, providing a reliable operationalisation of the value of the regular bottle. Control variables, such as age (discretised), sex, education, job, and economic status, are gradually added to the equation to ensure the robustness of the findings. These categorical variables are treated as dummy variables, with specific reference groups indicated in Table 3.

The estimated parameter β is positive and statistically significant ($P < 0.01$), indicating that consumers who value the regular bottle of wine more are willing to pay a higher price for the "precision viticulture" attribute. This relationship remains stable and robust across different control variables. This finding suggests that winemakers producing expensive wines could benefit from upgrading their winemaking techniques to incorporate precision viticulture (Bellvert et al., 2020), enhancing consumer appreciation and potentially saving water and energy. Additionally, the analysis reveals that being male reduces the WTP for "precision viticulture" compared to females, with significant results at varying significance levels. This implies that females are more likely to value the "precision viticulture" attribute than males. Winemakers targeting a female consumer base may find value in transitioning to sustainable production methods like "precision viticulture", aligning with the growing trend of women showing greater sensitivity towards sustainable consumption practices (Bloodhart

TABLE 3 Relationship between the value of regular wine and the "precision viticulture" attribute

	(1)	(2)	(3)	(4)	(5)	(6)
P_{bottle}	0.355***	0.356***	0.351***	0.359***	0.363***	0.362***
	(0.090)	(0.091)	(0.090)	(0.090)	(0.093)	(0.094)
Age		0.002	0.001	0.006	–0.005	–0.005
		(0.020)	(0.019)	(0.020)	(0.031)	(0.032)
Gender (*female*)						
Male			–1.203**	–1.170**	–1.111*	–1.117*
			(0.584)	(0.585)	(0.598)	(0.603)
Education (*middle school*)						
High school				–2.205	–2.083	–2.095
				(2.124)	(2.163)	(2.179)
University				–1.072	–0.922	–0.937
				(2.120)	(2.167)	(2.184)
Post-graduate				–2.316	–2.272	–2.268
				(2.103)	(2.147)	(2.163)
Job (*unemployed*)						
Student					0.872	0.801
					(3.707)	(3.764)
Paid worker					1.377	1.309
					(3.620)	(3.690)
Self-employed					–0.013	–0.048
					(3.908)	(3.950)
Retired					1.481	1.441
					(3.851)	(3.896)
Economic status (*low*)						
Middle						–0.155
						(1.260)
High						–0.226
						(1.354)
Cons	–0.229	–0.334	0.196	1.726	0.831	1.067
	(0.800)	(1.251)	(1.264)	(2.429)	(4.418)	(4.674)
R^2	0.090	0.090	0.114	0.141	0.147	0.147

Note: *, **, *** P < 0.1, P < 0.05, P < 0.01

SOURCE: AUTHORS' CALCULATIONS

and Swim, 2020). Despite the model's low explanatory power (as shown by the low R^2), it provides valuable insights into consumer preferences and behaviours related to wine attributes. The model is unsuitable for predictive purposes due to its limited ability to explain variance in bids.

4 Conclusions

This study explores consumer perceptions of "precision viticulture" by combining van Westendorp's PSM analysis with BDM experimental auctions. The price range for a regular bottle of "Falanghina del Sannio" wine is 6.07 to 8.06 Euros, with an optimal PSM price of 6.99 Euros. The BDM auctions further estimate consumers' WTP to upgrade to a bottle featuring the "precision viticulture" attribute, holding other factors constant. The empirical demand for the attribute "precision viticulture" correctly shows a negative slope. A price of 2 Euros for the attribute "precision viticulture" maximises the empirical revenues.

The total value of the upgraded bottle of wine was calculated after combining the optimal value from van

Westendorp's PSM analysis and the value of the attribute "precision viticulture" from the BDM experimental auction. The price elasticity was found to be –3.31%. Additionally, an OLS analysis was conducted to estimate the impact of the price of the regular bottle on the "precision viticulture" attribute. The results indicate a positive and significant relationship, suggesting that as the price of the regular bottle increases, the WTP for the "precision viticulture" attribute also increases. Moreover, being female is associated with a higher valuation of the "precision viticulture" attribute. These findings remained robust even after controlling for additional variables.

These findings offer valuable insights for policymakers aiming to promote sustainable agricultural practices and for wine producers considering investments in precision farming systems. Policies incentivising sustainable production, such as subsidies or certifications, could increase the market appeal of wines featuring these innovations. Furthermore, understanding the value consumers place on sustainability could encourage wine producers to adopt sustainable farming techniques and provide a useful benchmark for pricing wines produced with precision farming. Wineries can leverage these insights to strategically price and market their products, targeting consumer segments most receptive to sustainability, particularly high-value wine buyers and female consumers.

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