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Keynote article

Risk, uncertainty, crises management and public intervention in agriculture

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Abstract. Climate variability and extremes, socio-economic conditions, crisis and market shocks are among the main factors determining risk in the agricultural sector. Drought, heat stress, flood, market volatility among the others, have caused heavy losses in the recent past and both the occurrence and intensity of these extremes are expected to increase in the coming decades. Emerging and re-emerging diseases represent a serious concern for the future of agriculture. Here, we provide a synthetic overview of the theoretical framework that could lead public intervention in this specific field and discuss measures that have been taken to reduce economic losses for Italian farmers. We also tried to highlight the difference between risk and uncertainty that in a new global scenario will substantially characterize the reliability of empirical analyses in this complex research field.

Keywords: risk management in agriculture, green portfolio, public support, risk vs uncertainty.
JEL codes: Q14, G18, G22, G32.

HIGHLIGHTS

- Need for radical reformed risk transfer tools and greater public intervention both ex-ante and ex-post.
- defining a theoretical framework for a correct approach to income risk management in agriculture built on the "green portfolio" concept.
- highlight the difference between evaluating risk and uncertainty, which will pose new challenges when dealing with risk management in agriculture.
- risk management in agriculture cannot be identified by crop insurance subscription alone.

1. INTRODUCTION

Winter 2021 in Italy was the warmest on record for the third consecutive year, with rain and snowfall decreased by 50%; furthermore, spring and summer 2022 saw a long period of drought and above-average temperatures (JRC Global Drought Observatory, 2022). These unusual weather conditions have brought the topic of climate change back to the fore and have forced farmers to take a closer look at crop insurance coverage and other methods of stabilizing farm income, including the role of public interventions.

It would seem that we are now in a moment when farmers and consumers alike are painfully aware of the precariousness of Italy's food supply and people are beginning to realise that permanently stocked shelves cannot simply be taken for granted.

It has been established that agriculture is arguably the sector of production where factors outside managers' control are more heavily responsible for the final result of the enterprise, something that has contributed to the development and acceptance of forms of public intervention aimed at reducing income variability that have no parallel in other sectors of the economy (Moschini, Hennessy, 2001; Wright, 2006). The nature of the risks facing farms has changed greatly in recent decades, as have the potential negative impacts of different forms of risk: production, markets, financial, and institutional. What is often overlooked, however, is the changing nature of the needs of farmers, who will surely require radically reformed risk transfer tools (new crop insurance, financing, loans) and greater public intervention, both ex-ante and ex-post.

However, the recent climatic trends mean unpredictable economic performance for farmers. This, together with other reasons, has traditionally fostered legislators around the world to build agricultural policies that are designed to shield farmers from the inherent risks associated with food production.

Indeed, policies to develop infrastructure in the agricultural sector have increasingly given way to policies directed at price and yield stabilisation mechanisms. In the same vein, of the many tools available for income risk management, the most heavily applied continues to be crop insurance.

Since 1970, in Italy, there has been a complex structure of state insurance subsidies for the primary sector. Priority has been given to subsidies for insurance policy premiums and ex-post interventions to compensate farmers for damages in the event of a natural disaster.

The main aim of this paper is to clearly define a theoretical framework for a correct approach to income risk management in agriculture built on the "green portfolio" concept, where private risk management tools are used alongside public interventions. The paper also tries to highlight the difference between evaluating risk and uncertainty, which will pose new challenges when dealing with risk management in agriculture.

The theoretical framework is therefore instrumental in defining the scope of intervention for a variety of public and private instruments that can be applied to income risk management for farmers. The synergy between different instruments highlights the complexity of the issue and suggests that simplistic solutions will not suffice. In order to indemnify the agricultural sector against future risks in the long term, an innovative approach to risk management is required, one which also incorporates a strong relationship between banks and agricultural businesses and can finally tackle the criticalities amplified by the de-specialisation of credit introduced under the Basel II Accord (Adinolfi *et al*., 2012).

Of course, the difficulties in accessing credit (credit crunch) must also be taken into consideration, not doing so would be short-sighted and result in a strategy destined to fail the Italian agricultural sector. Similarly, it is necessary to bear in mind that Italy has reduced public spending for the primary sector and that forecasts predict a decline in the value of national land assets. Indeed, in the next 80 years, it is expected that Italy's farmland will lose 50 billion euros in value in the "best-case scenario" of a +1°C temperature increase; in the "worst-case scenario" of a +5°C increase, the loss is estimated to reach 185 billion euros) (IFPRI, 2022). This is rarely taken into account but suggests an urgent need for evolution – and revolution – in public intervention, which must be better focused on the implementation of new risk management tools and strategies.

The need for new management models, both from an economic and financing perspective, is now undeniable; they can no longer be overlooked in the scientific, business and political debate.

This is especially true given the changing face of the Italian primary sector in recent years; the number of farms run by university or high school graduates has increased significantly (up 15,000 for the former; 65,000 for the latter), and the total number of farms run by young people has risen sharply (an increase of 17% in the last three years), just like the percentage of farms run by women, with a rate higher than the EU average (Unioncamere, 2020). Despite the counterfeits and fraudulent use of "Italian sounding" branding, Italy's food products preserve their feature of uniqueness as derived from peculiar pedo-climatic conditions and from centuries-old techniques and heritages in the long history of "Italian food artisanship", which can vary from region to region or even town to town. The "fragmentation" of Italian farms, often referred to as the fragility of the system, could be interpreted as a secular adaptation to the specificity and unique requirements of a multitude of different terrains. From this point of view, such an Italian farm model must be defended and supported; and new future scenarios require us to have a clear and courageous vision for its survival.

2. ANALYSIS OF RISK MANAGEMENT POLICIES

Economists tend to evaluate the effects of policies through the lens of economic theory, which allows them to arrive at objective indicators to measure the benefits of a given policy intervention. In cases involving high degrees of uncertainty, the theoretical framework that is most widely applied is the so-called "maximization of Expected Utility" (EU) (Moschini, Hennessy, 2001). However, careless use of this model can lead to invalid conclusions since they are dependent on the implicit assumptions that are fed into any given analysis. In this sense, three issues are often overlooked in the debate surrounding risk in agriculture.

The first issue is that measuring the benefits of policy intervention in terms of whether it increases or decreases the risks an economic actor is facing, depends on the whole distribution of possible results, not just on the expected value or the combination of mean and variance. This is especially true when the distribution of potential results is very asymmetric as is the case when there is a low probability of events which carry very serious negative consequences, or when the policy itself modifies the symmetry of distribution (e.g., taking out an insurance policy or using other financial aids). The simplification of analysis based on the EU method, such as median-variance approaches, can lead to very serious errors in assessment in cases like the aforementioned (Hardaker, 2000).

The second issue is that theories of economic behaviour based on utility focus on the stability of consumption and not of income (Modigliani, Brumberg, 1954). For this reason, the important role of savings and loans as a means of keeping consumption less variable cannot be overlooked. Unless there is a very substantial change in income and/or the interest rate is very high, the cost-benefit of a transient change in income will be quite low, since stable consumption levels can be maintained through the careful use of savings and credit (Friedman, 1957).

The third issue, too often overlooked in the analysis of benefits tied to risk in agriculture, is that risk exposure at the farm level should be analysed in the context of the wider portfolio of economic activities in farming families. Even for specialized farms, the potential benefits of reducing risks associated strictly with farming activities should always be assessed in conjunction with how they might affect the entire potential family income (e.g. off-farm employment, and other financial activities).

In the literature (Chavas *et al.*, 2010), risks have been classified in various ways. One traditional classification distinguishes production risk *stricto sensu*, which is the possibility of lower-than-expected output quantity and/or quality, from price or market risks (either inputs' price rising or output's price falling after production commitments have been made), personal risks (i.e., risks of personal illness, accidents, death) and institutional risks (i.e., the possibility that relevant norms and regulations would change unexpectedly). Although most of the discussion on risk in agriculture has focused on production risks, the other dimensions are becoming more and more relevant in modern agriculture.

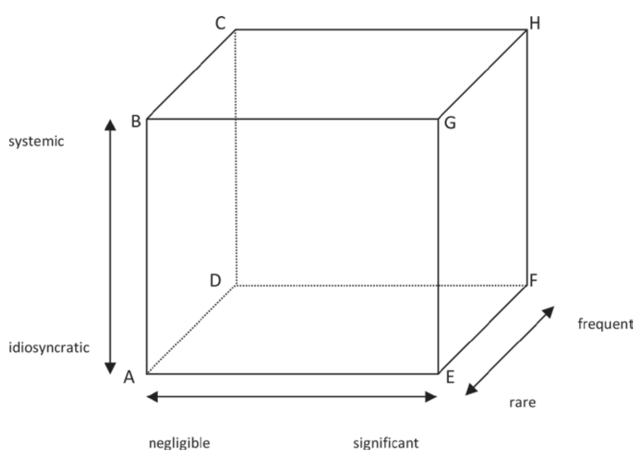
In this perspective, it may be appropriate to introduce a three-dimensional scheme ("risk box") classifying the events that generate risk, according to different degrees of frequency, damage intensity and correlation (Cafiero *et al.*, 2005).

Depending on the combination of these dimensions, a harmful event can be located in a three-dimensional space (Fig. 1) whose vertices correspond to the most extreme forms. Even if, arguably, no real event corresponds perfectly to one of these extreme forms, such classification serves to underline the combination of the most relevant characteristics to choose the most suitable management tool. Except for types of events located at G and H vertices of the box, namely those events that lead to potential and very serious consequences, and for which the only possible strategy should be to elude them (e.g., by avoiding activities in exposed environments), most of the frequent risks associated with "risk box" characteristics can be managed effectively.

A possible classification of management strategies differentiates whether the risk is maintained (so the potential consequences are yet to come), avoided, reduced, or transferred.

When the potential harm is limited (A, B, C and D vertices), farmers can manage the risk by taking *a posteriori* action, known as "risk coping" (Wright, Hewitt,

Fig. 1. The three dimension of risk – "risk box".



1994). The most common risk coping strategy is using savings to avoid reducing consumption. This results in a type of self-insurance policy, allowing the impacts of a harmful event to be "spread" across a longer time frame, in the hope that conditions will improve in the future and that saving reserves can be rebuilt for the next event. This strategy is only feasible if there are enough financial resources to start with or easy access to credit. Its cost is the cost opportunity of the financial reserves that have to be mobilized or the interest paid on the loan.

On the other hand, when the potential harm is very high, the best action to take is probably to avoid the risk altogether, which, however, implies big decisions such as the following: moving the farming activity to an area less susceptible to the risk; investing in physical infrastructure (irrigation systems against drought, protective nets against hail); undertaking actions of so-called *income skewing* (Dercon, 2004), activities that are less averse to risk but are less profitable. This last one is a widespread practice in rural areas of developing countries where the scarcity of financial resources and poor market access make alternative risk management or risk transfer strategies impossible.

As underlined above, in many cases, the best strategy to reduce risk is diversifying sources of income. Farmers all around the world have been doing this for decades, either by diversifying agricultural production (e.g., by diversifying crops or adding crops to livestock farming) or investing some family resources in extra-agricultural sources of income. The cost of this strategy is the loss of the potential benefits of specialisation and, depending on the context, this potential loss can often be less than the cost of, for example, commercial insurance coverage.

As in the case of risk coping, risk transfer can take many different forms. However, the efficacy of risk transfer strategies heavily depends on information sharing between all interested parties. For this reason, a fourth dimension could be added to the "risk box", in order to classify events based on "predictability", intended here as the ability to associate a reliable probability distribution with the event. Predictability is a crucial condition for assessing the cost of a given risk management strategy and is a basic requirement for both insurability, that is, the possibility of establishing correct premiums for feasible insurance contracts and the potential for hedging through the use of financial derivatives. When faced with an unpredictable event, since there is not sufficient information on which to base a probability distribution analysis of potential harms, a private market of risk transfer cannot be established. If the consequences of an uninsurable event are grave, the only hope to avoid bankruptcy is relying on some sort of public solidarity. Table 1 summarises the best possible strategies for each extreme event in the "risk box".

3. PUBLIC INTERVENTION FOR RISK MANAGEMENT IN AGRICULTURE; A HISTORICAL FAILURE

Public intervention in agricultural risk and crisis management started in Italy in 1970 with law No. 364, which established operations of the Fondo di Solidarietà Nazionale (FSN) with two functions: compensation for

Tab. 1. Risks, strategies and management tools.

Type of event	Examples	Strategy	Best action when the event is predictable	
			Ex-ante	Ex-post
A – Idiosyncratic, rare and negligible	Minor personal illnesses	Retain	None	Coping
B – Systemic, rare and negligible	Minor epidemics (like the flu)		Vaccination	
C – Systemic, frequent and negligible	Minor droughts Price swings		Investments, savings	Coping, storage management
D – Idiosyncratic, frequent and negligible	Personal illnesses. Minor car accidents		Mutual insurance	Coping
E – Idiosyncratic, rare and significant	Hail, Fire, Theft	Not retain	Market-based insurance	Rely on public solidarity
F – Idiosyncratic, frequent and significant	Livestock illness		Relocate; hedge on financial markets.	None
G – Systemic, rare and significant	Earthquakes, tsunamis, major epidemics (like the BSE)		Hedging on the global market (CAT bonds)	Rely on public solidarity
H – Systemic, frequent and significant	Drought in the desert!	Avoid	Public investments, relocation.	

farmers suffering a sudden and severe drop in their farm income for reasons beyond their control and support to crop insurance. The law that established the FSN also authorized operation of farmers' mutual associations (the Consorzi di Difesa), which are intended to play two roles. The first is the collection of farmers' insurance demands (mainly hail until 2003) at the provincial level and their placement to insurance companies; the second is the coordination and enforcement of common preventive measures. The mutual approach was intended to reduce the usual problems of asymmetric information and improve power relationships in fixing insurance premiums. Despite the presence of subsidies up to 65% of actual premiums, the diffusion of crop insurance in the Italian agriculture has been rather weak: the share of insured value on total crop production has never been more than a maximum of 20%. The products covered by insurance are mainly fruit crops and vineyards (up to 65%). The past two decades have been marked by tackling the low insurance demand and a considerable amount of public funds has been poured into the system; this raises the crucial question as to whether scientific representation and related knowledge claims used in the problem framing and formulation of solutions (e.g. multiperil insurance) have been incomplete or incorrect.

From the above, we could consider that public interventions in Italy have largely failed (Cafiero *et al.*, 2007; Capitanio *et al.*, 2011; Enjolras *et al.*, 2012; Santeramo *et al.*, 2016). This is because these policies have probably lost sight of the sheer complexity of the interrelations between the myriad of risks that are an inherent part of farming, and instead exclusively subsidized farm insurances and neglected the potential role of other risk management tools and strategies. Also in 2013, whereas throughout the CAP reform process mutual funds and the income stabilization tool (IST) were introduced under reg. 1305/2013 art. 35-38, Italy chose to continue what has always been done: subsidize traditional insurance policies (Severini *et al.*, 2019; Cordier, Santeramo, 2020).

If, on the one hand, the timid conservative approach can be justified for pragmatic reasons (spending efficiency, and preservation of a rigid system with evident risks of "*rent-seeking*"), on the other, it has created the conditions for an urgent need to broaden horizons and look towards a completely different system.

As highlighted (Cafiero *et al.*, 2007; Capitanio *et al.*, 2011; Enjolras *et al.*, 2012; Santeramo *et al.*, 2016), the demand for insurance is generally low and highly concentrated in Italy; there is a dramatic gap between different parts of the country and very few question its real causes. Many factors limit the uptake of subsidized farm insurance, especially in central and southern Italian regions, but the main ones are the following: i) the propensity to take a more traditional and local approach to farm management rather than seeing their farms as competitive businesses; ii) extremely diversified production with two or more different annual crop cycles and, more importantly, less exposure to the risks typically covered by insurance policies (e.g., hail); iii) smaller-scale farms in southern Italy compared with the centre and north of the country, which have to tackle greater administrative complexities to join risk management systems by comparison to bigger farms with more homogeneous farming activities; iv) lack of action by *Consorzi di Difesa* in the centre and south of Italy compared with a more consolidated tradition of these associations in northern Italy; v) insurance policy models designed predominately on the agronomic and climatic needs of the northern regions; vi) lack of innovation in public management models.

Therefore, one might wonder how we got to this point. One possible answer could be the inertia of the public-private system, which is impervious to any attempt to innovate production, despite the evolution of EU legislation (most recently with the Omnibus Decree of 2017 (reg. EU 2393/2017). Political action comes at private costs for those who implement any kind of state intervention, while the public benefits will remain largely external to those individuals. It therefore follows that those individuals are less willing to actively participate in building new policy measures; those who choose to undertake this difficult task will tend to do it for private benefit. The absolute unawareness of farmers of the inefficiencies in both policy construction and expenditure in the agricultural sector has no other explanation; farmers normally ignore public action, and the state is therefore an unreliable "agent". Lawmakers and bureaucrats have vested (and legitimate) interests which systematically lead them to favour one course of policy action over another, often wittingly or unwittingly to the detriment of the community as a whole. Results of public intervention in crop insurance in Italy can be summarized as follows (ISMEA, 2022): a very low rate of participation (never above 20% of Gross Domestic Product (GDP) insured in the last 15 years); a huge divide between different areas of the country (80% of all insured GSP located in a few provinces in northern Italy); the creation of an anti-selective portfolio with growing costs of reinsurance (only businesses that are deemed "risky" by the parameters of the insurance contract are insured); 51% of the budget allocated for the National Measure (Measure 17) for the programming period 2014-2020 has been guaranteed by six southern regions; around 30% of the National Measure funds are intercepted from Trento and Bolzano, which account for less than 3% of Italy's gross saleable vegetable production that represents up to 90% of the overall insured production (MIPAAF, 2015; ISTAT, 2022).

In this scenario there are at least two critical elements to be highlighted:

1. The projections for future climate change indicate that the south of Italy is one of the areas at the highest risk of erosion and yield loss (Bozzola *et al.*, 2018; Chavas *et al.*, 2019);
2. The geographic concentration of the crop insurance market in Italy negatively affects price dynamics, since the cost of the premiums has increased by 44% in recent years (ISMEA, 2022).

This is because of the massive concentration of certificates of insurance that reduces the ability of insurance companies to diversify risks among the insured pool.

This trend seriously jeopardizes the continued subsidization of 65% of policy premiums, even to those farmers who have historically been insured; without a considerable increase in budget, it is plausible that the agricultural insurance system in Italy will collapse.

As for the 2014-2020 programming period, from 2023 on there will be an important new addition to the National Mutual Fund, the so-called METEOCAT[1] (Zaccarini, Lasorsa, 2020), which will be financed through a 3% deduction from direct farm payments and co-financed with resources coming from the European Agricultural Fund for Rural Development (EAFRD), with annual funding estimated at around 350 million euros.

METEOCAT, which was strongly advocated by Italy during the new CAP discussions, is a tool that intervenes in case of catastrophic risks (frost, drought and flood), and covers all Italian farms receiving direct payments. The idea is that it would intervene as a compulsory first-level coverage to compensate at least 50% of the average national damage from catastrophe. This would then encourage Italian farmers to join the second level of coverage, which includes the subsidized system of agricultural insurance policies, mutual funds and Income Stabilization Tools (IST).

Nevertheless, the adoption of such ex-post intervention could imply the risk of umpteenth failure, as Italy has experienced for decades, or rather of another waste of public money.

Indeed, in the last twenty years, Italy has experienced an annual average of verified damages equal to 1.2 billion euros; the National Solidarity Fund (FSN) has effectively liquidated an amount of money equal to 4.8% of these damages on average (MIPAAF decree, several years). So, practically nothing. It is quite clear that using these resources based exclusively on the indemnity principle will add no real economic value.

Another sensitive issue is the marginal role that Mutual Funds and the IST have been given in the forecasts for post-2023 CAP, which could play an important role in some management risk types (Trestini *et al.*, 2018). The growing price volatility in energy and agricultural commodities in international markets, with prices peaking in the first trimester of 2022, sparked an important debate on the repercussions for the economic resilience of farms, particularly in the livestock sector, and opened a reflection on how and to what extent State intervention could mitigate undesirable knock-on effects. Persevering with a system of actions aimed at identifying risk management with the underwriting of an insurance policy can only be justified if public decision-makers are willing to accompany the necessary change.

4. RISK AND UNCERTAINTY: NEW METHODS FOR NEW SCENARIOS

When does managing uncertainty become managing risk? Generally, it is possible to distinguish between two types of uncertainty: "ambiguity" and "risk". This distinction depends on whether the uncertainty can be quantified or not; risk is quantifiable, and ambiguity is not.

This simple distinction was first introduced by Knight (1921) in the early 20th century and has subsequently become known as "Knightian uncertainty". The thought experiment introduced by Ellsberg (1961) adds some clarity to the distinction.

If we imagine we have two urns in front of us, each containing 100 balls. In the first urn, we know that half of the balls are white, and half are black; in the second urn, we do not know the colour distribution. The first urn, therefore, represents a situation where the uncertainty is quantifiable, and risk is an important concept. Instead, in the second urn, the key concept is ambiguity (the aforementioned "Knightian uncertainty"), that is uncertainty that cannot be quantified.

In many works on risk management in agriculture attention has been focused on the concept of risk, therefore on what happens in the first urn; the situation of the second urn, however, is covered by an area of research that is still relatively unexplored, but that will become crucial in the light of the frequency of weather events caused by climate change and by the heightened price volatility of agricultural commodities (De Castro *et al.*, 2012).

[1] Set up under art. 1 of Italy's 2021 Budget Bill 234/2021 commas 515-519, for the implementation of UE reg. 2115/2021 (art. 19 and 76),

Due to climate change that will modify the effects of weather on crop yields, nowadays exposure to pervasive production risks, brought upon by biotic and abiotic stress, represents a fundamental determinant of agricultural productivity and food insecurity (Hennessy, Moschini, 2001; Just, Pope, 2002; Chavas, 2004). Since the 1970s scholars in agricultural economics have developed empirical tools to model the distribution of yields and identify potential ex-ante risk management strategies (Just, Pope, 1978; Antle, 1983). But the estimation of the distribution of yields is challenging for several reasons. First, as adverse risk shocks are located in the lower tail of yield distributions, a simple mean-variance analysis is not sufficient to evaluate the effects of possible crop failure (Antle, 1983; Di Falco, Chavas, 2009; Chavas *et al.*, 2019; Chavas *et al.*, 2022). Second, genetic selection and improved management have affected yield distributions both across crops and over time. And climate change has generated concerns about its adverse effects on crop yields and agricultural production risk (Ray *et al.*, 2012; Lobell *et al.*, 2014; Nelson *et al.*, 2014; Gammans *et al.*, 2017; Arora *et al.*, 2020). Third, crop yields vary in space: agro-climatic conditions and soil fertility change across locations (Jones *et al.*, 2013; Amundson *et al.*, 2015; Stevens, 2018). Capturing the spatial distribution of yields requires estimating a multivariate distribution. And establishing linkages between the spatial and temporal agricultural risk and food insecurity remains difficult.

In methodological terms, the correlation between risk and food security (or food insecurity) is therefore a critical challenge for the kind of analysis that researchers will need to develop in coming years, precisely about the "re-mixing" of the colour distribution in the aforementioned urns. In practical terms, when research focuses on agricultural risk and its linkages with food security, either weather (including drought, flood, cold spell, heat waves, etc.) or market shocks are the main sources of risk in agricultural production, as is well-known. Even if you are only analyzing ex-ante production risks, perhaps weather instances in previous years should be included, so that weather shocks can be serially correlated.

The key point is that if we included them as explanatory variables, they would be treated as if they were "known". This would be appropriate if we wanted to develop an ex-post analysis of agricultural production (e.g., to investigate how droughts or heat waves contribute to low yields). But, weather shocks are typically not known ahead of time (e.g., weather conditions during the growing season are not known at planting time). It means that a risk analysis of agricultural production must be conducted ex-ante, treating weather shocks as uncertain. This is a key motivation for risk analysis: try to treat unanticipated weather shocks as random variables (Chavas *et al.*, 2019).

It will be increasingly difficult to make predictions with "certainty" about the world of farming, what future climate patterns will look like and/or how market prices will trend. As a result, the kind of analyses based on the Arrow and Pratt model (Arrow, 1964; Pratt, 1964) will be relegated to a minority role. The Arrow-Pratt measure of risk aversion has been a theoretical cornerstone to describe productive decision-making behaviour. The authors identified the coefficient of absolute risk aversion, which is the measure of individual aversion to changes in levels of wealth; the coefficient of relative risk aversion, however, identified an agent's risk aversion to changes in wealth and risk factors of the same proportion.

To meet the theorem of expected utility it is crucial to identify the benefit (utility) derived from the elimination of risk to the future income, thereby maximizing the utility for individuals.

Different agents have different levels of risk aversion. For a risk-averse investor, there is a trade-off between the level of yield and the level of risk. In other words, a farmer could accept low returns if the implicit risks of the production system are low or aim at high returns if the risks of the production portfolio are high; behaviours like these reflect the aversion to risk.

However, this approach suggests that farmers "act" as in the case of the first urn. That is to say, their choices are predictable; farmers base their decisions regarding production on their perceptions of the likelihood of future events and, acting individually, they react differently to policy and price changes based on their aversion to risk and levels of wealth.

There is a consensus in the literature that farmers are averse to risks and this declines as their levels of wealth increases.

This attitude to production choices is known as Decreasing Absolute Risk Aversion (DARA) and is accepted as "rational behaviour" for agents who are averse to risk.

The bottom line is that more risk-averse farmers will be more likely to make less risky production choices; if potential income is equal, they will naturally lean towards those choices that they perceive as having "greater future certainty".

This may all seem pretty self-evident, perhaps obvious.

If, however, we accept the hypothesis that after the first urn, we turn to the second urn, the embarrassment would vanish, and we realise that the methodological questions will be decisive in determining the robustness of the analysis that will form the basis of economic policy on agricultural risk management.

In different terms, the less information individuals have (uncertainty vs. risk), the more they fail to sufficiently discriminate between different levels of likelihood (Tversky, Kahneman, 1992). The behavioural economic literature shows aversion towards uncertain compared to risky choices: individuals prefer known probabilities over unknown probabilities, even if the known probability is low and the unknown probability could be a guaranteed win (Ellsberg, 1961). Recalling the urns, if winning is achieved by drawing a white ball. when asked this question, most people opt for the known urn. However, if they win when drawing a black ball, they also opt for the known urn. This decision contradicts the notion of probability: people act as if the chance of drawing a white ball from the unknown urn is less than 50%, but also as if the chance of drawing a black ball from that same urn is less than 50%. This so-called Ellsberg paradox illustrates our initial statement: when asked to choose, individuals prefer risk over uncertainty.

Moreover, in the theoretical setting outlined above preferences are given. The utility function is taken to be a fundamental individual characteristic. As with demand elasticity, risk aversion coefficients should be estimated empirically from representative samples of the population, and projections outside the sample should always be taken with some degree of caution.

Unfortunately, as opposed to traditional demand estimation, in this case it is virtually impossible to find sufficient data to identify the structure of the risk preference from, for example, the underlying distribution of the relevant variable. For example, does the fact that a farmer does not buy insurance mean that he is not risk averse, or that he does not believe a bad outcome would occur? The simple observation of not buying insurance could be used as evidence of lack of risk aversion, if one is willing to assume the probability distribution of outcomes, or of evidence that the subjective distribution of outcomes is not very spread if one assumes a certain degree of risk aversion.

As difficult as it might be, however, to distinguish between the two is imperative from a policy point of view. In the previous example, if the farmer is not risk averse, why should he be compensated in the case that a bad outcome occurs and he decided not to insure? After all, no government would ever engage in compensations to unlucky gamblers. Different would be the case if a real damage occurred for lack of sufficient information on the probability distribution of the events, in which case a compensation might be justifiable.

Put in simpler ways, it is always possible to justify an intervention in favour of an agent or a group of agents by assuming that they suffer a damage facing whatever the current conditions are. The point is that the customary habit of analysts in this case has been to assume a certain degree of risk aversion, which would invariably lead to "discovering" that facing a risky prospect implies a damage and therefore that an intervention is justified, without taking the care to check whether the assumed degree of risk aversion is consistent with other observed behaviour of the agents.

A better "code of best practice", as Hardaker suggests, would be to focus on trying to address the "objective" probabilities of the possible outcomes, and therefore to make the best use of the observed behaviour to try and assess the real propensity of farmers towards risk, and perhaps one would discover that «agricultural economists have paid too much attention to risk aversion» (Hardaker, 2000, p.13) and that «from a social welfare perspective, most risks faced by individual farmers or groups of farmers are very unimportant.» (ibid.)

5. FINAL CONSIDERATIONS

Due to the multiplicity of risks faced by farmers, a first general observation that can be inferred from the Italian context as described is that it would be unrealistic to identify the stability of farmers' incomes by the adoption of one single risk management tool.

One of the aims of this work is to frame the theoretical aspects that should inform policy design to manage risks and crises in agriculture in the context of an advanced economy.

The lessons to be learnt from what has previously been discussed can be summarised as follows:

1) The importance of risk factors and their potential positive or negative effects on farmers must be well understood ex-ante (Tinbergen, 1952 and 1956).
2) The need to determine the consequences of those risks in terms of benefits and therefore the value of implementing public risk reduction policies; this implies that the risks farmers face must be measured in terms of their potential effects on the consumption levels of farming families and not on current levels of income. In many cases, consumption depends on the anticipated permanent income levels of the whole family. The theory of consumer behaviour postulates that the yearly level of consumption is not directly linked to current income, but rather to the expected value of long-term wealth, and this is widely confirmed by the empirical evidence. This emphasizes the role of savings and borrowing as private risk management tools.
3) Such a preliminary analysis would recognise the fact that there are risks that can be managed effi-

ciently by farmers, both through the diversification of income sources and the use of mechanisms such as savings and credit, which can help farmers deal with limited fluctuations in income without the need for state subsidies. Since the work of Friedman and Savage (1948), and Markowitz (1952) who discussed the expected utility approach to the cases of monetary outcomes, it is clear that the argument of the von Neumann and Morgenstern (VNM) (1944) utility function should be wealth, not income, i.e. a measure of a monetary stock and not of a flow, and there is a good reason for that: what really provides utility should never be considered to be "money" per se, but rather, it is the level of consumption that money permits that individuals care about. It is well established that consumption is much more closely linked to wealth, or what we could term as "permanent" income rather than to current or "transitory" income (Friedman, 1957). Of course, income contributes to wealth formation, and transitory fluctuations in income may have consequences. However, the impact in terms of welfare of a temporary change in current income, and therefore what would justify public intervention, is admittedly much lower than the impact of a similar change in permanent income.

4) On the other hand, when the predictability of events is so limited that is not possible to formulate any form of preventative action, or when the potential harms are too great for a farmer to independently take on, there is no other alternative than some form of state subsidy and transfer of risk to third parties.
5) To avoid inefficient spending of public money, a clear distinction should be made between the normal risks of doing business and truly disastrous events. Farmers should be mainly responsible for the former without recourse to state intervention.
6) Subsidies could take the form of direct payments or financial assistance to pay off the interest on loans taken out to rebuild damaged farms.
7) In the medium to long term, subsidies should be aimed at supporting farmers to implement preventative actions that reduce the scale of damage caused by natural disasters, for example giving farmers incentives to move away from areas that are particularly exposed to risks of natural disasters or to invest in protective infrastructure. Furthermore, public spending could be used where there are large economies of scale or where investment in protective infrastructure can be considered public goods.
8) For normal risks of doing business, state intervention should be limited to determining the necessary conditions for farmers to develop and strengthen their capacity to manage risks by using private instruments such as insurance, credit and financial markets. In this case, state intervention should also aim to promote the activities of private markets.

Various actions could help move us in this direction:

9) Creating institutions and information activities to promote demand for private sector tools to manage risk, whilst fostering greater competition on the supply side.
10) Promoting precautionary saving, through direct and indirect incentives, e.g., tax benefits, to increase farmers' resilience to less serious risks at the farm level.
11) Promoting a greater concentration of demand for risk management tools to give farmers better access to insurance, credit, or financial markets. In this case, supporting the operation of mutual funds can be an effective way to incentivize the development of risk markets in Italy. In addition, a greater concentration of demand will help internalise monitoring costs, thereby increasing the scope of mutual funds for the type of risks that are, by their very nature, difficult to transfer because of the problem of information asymmetry.
12) Securitisation of the risks associated with climate-related impacts must also be considered as a way of leveraging public investments in the agricultural sector, especially for ex-post intervention to compensate for damages (e.g., Cat bond). Given the fact that extreme weather events are increasing in number and intensity, it will be ever more difficult to continue compensating farmers without this kind of financial leverage.

In light of this, farm access to credit plays a fundamental role. The capitalisation and profitability of farms will be the two key elements to access credit and contain costs; credit will be sorely needed to make investments, especially in innovation.

This will mean that farmers need to keep detailed and transparent accounting, which, unfortunately, is not happening on a significant proportion of farms. This study has highlighted the need to continue further down the path of developing assessment systems that can accurately describe the real state of the primary sector. Classic methods to assess credit rating tend to produce high scores for farms because of their high levels of capitalisation, however, these scores can overestimate the real conditions of farms' balance sheets and consequently predict a low risk of default for the majority of farms.

The greater exposure to market risk and the new rules that have changed the conditions of access to credit for farmers, however, make this option more difficult than in the past; data resulting from analysis (ISMEA, 2019) reveals farmers' propensity to avoid taking on debt, highlights the need for many farmers to reorganize their assets and management structures.

In the Italian context, detailed economic data on farms can be difficult to gather because farms tend to be smaller and in many cases are set up in such a way that they are not legally required to provide financial statements or need only to present a very brief overview. For this reason, the data provided by the Farm Accountancy Data Network (FADN) archive is very important, especially given its standardisation of data inputs, making comparisons easier to evaluate.

To conclude, we can say that there is a consensus that all actors who care about the fate of farms, the quality of our products and the beauty of our countryside will no longer be able to procrastinate or get around the unavoidable evolution the sector requires; from the era of risk management to the era of uncertainty management. Precious time, even years actually, has already been wasted on building an effective and efficient system to protect agricultural incomes.

Yet if we continue with the inertia of the status quo, a large part of the productive sector, and a large part of the traditions and landscapes of rural Italy, will cease to exist.

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Research article

Weather Risk Management in Agriculture Using Weather Derivatives

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Abstract. The purpose of this paper is to examine weather risk management by application of weather derivatives in agriculture and evaluate the hedging efficiency. Agriculture is a sector highly sensitive to meteorological elements that affect the yield of many crops. The underlying weather indices depending on temperature, rainfall and wind speed are analysed. Pricing follows the index modelling method using the Burn analysis valuation for fair premium calculation. The proposal of hedging strategies against excess rainfall in the crop cycle using weather options for Kosice region in the east of Slovakia is investigated and discussed. Results show that the weather derivatives application in weather risk management reduced the yield volatility in agriculture.

Keywords: weather risk management, weather option, rainfall index, burn analysis, hedging efficiency.
JEL codes: G130.

HIGHLIGHTS

- The risk of unfavourable price movements impacts on the yields from agriculture business.
- Temperature, rainfall, and wind speed data serve to model the underlying weather indices and option pricing.
- Weather hedging strategies against excess rainfall in the crop cycle using call and put options are the new tools in weather risk management in agriculture.
- Adoption of the weather derivatives can reduce the yield volatility of producers.

1. INTRODUCTION

Weather has had a growing impact on the economy in the last decades. Štulec (2017) states that approximately four-fifths of the world economy is directly or indirectly exposed to the weather.

Weather impact can be either catastrophic or non-catastrophic. Catastrophic weather includes low-probability events that cause huge financial damage, such as floods, hurricanes, and tornadoes. For example, the paper by Falco *et al.* (2014) studies the role of financial insurance in farmers' hedging against the implications of climate change. Traditional insurance can be used to avoid high losses coming from catastrophic events, but it does not provide an adequate solution to mitigate financial losses caused by non-catastrophic weather conditions (Cyr *et al.*, 2010). Non-catastrophic weather refers to small deviations from normal weather with a high probability of occurrence (Brockett *et al.*, 2005; Bartkowiak, 2009). With the introduction of weather derivatives, subjects can now hedge their exposure to non-catastrophic weather events (Stulec *et al.*, 2016). Leggio (2007) states that companies use weather derivatives to stimulate sales and diversify investment portfolios.

Weather derivatives are contracts with the payoff depending on weather (Alexandridis and Zapranis, 2013a). The underlying weather asset is the weather index since weather is not a physical good. The weather market is incomplete in the sense that the underlying weather indices are not tradable. Most studies (Davis, 2001; Alaton *et al.*, 2002; Cao, Wei, 2004; Richards *et al.*, 2004; Benth and Benth, 2007; Zapranis, Alexandridis, 2009; Zapranis, Alexandridis, 2011) have investigated the weather derivatives including pricing. Alternative methods for pricing options when the underlying security volatility is stochastic are examined by Heston (1993), Alaton *et al.*, (2002), Brody *et al.* (2002), Benth (2003), Benth and Benth (2005), Turvey *et al.* (2006), Benth *et al.* (2007), Benth (2011), Benth and Benth (2011), Swishchuk, and Cui (2013).

The use of weather derivatives has proven to be effective in many industries (Yang, 2011). Agriculture depends more on the weather and climate than many other sectors. Business uncertainties and the environmental impact of farming justify the significant role that the public sector plays for farmers. The EU common agricultural policy, known as the CAP, supports the farming sector in all EU countries. The aims of the CAP are to help farmers and increase food security. The scientific literature (Schwalbert *et al.*, 2020; Chavas *et al.*, 2019; Trnka *et al.*, 2016; Cantelaube, Terres, 2005) has examined how crop yield is impacted by weather. Understanding of weather impacts on crop yield is an important aspect of food security. The relationship between weather and crop yields is very complex because weather affects both the quantity and quality of the crop. Crop cultivation is often influenced by several meteorological elements that are interrelated, for example, temperature, sunlight, humidity, rain, wind, snow, etc. (Stulec *et al.*, 2016). Weather extremes occur more often, having major consequences for plant cultivation and also livestock farming. Weather derivatives as non-catastrophic weather risk management solution for agricultural business are investigated in various studies (Chen *et al.*, 2006; Deng *et al.*, 2007; Taušer, Čajka, 2014). For example, Vedenov and Barnett (2004) studied the weather derivatives in corn, soybean, and cotton production in two regions of the United States. Spaulding *et al.* (2003) studied the efficiency of put option in hedging of corn and wheat production in Romania. Weather put option in corn production in Switzerland was investigated by Torriani *et al.* (2008). Markovic and Jovanovic (2011) examined the effectiveness of put option hedging in winter barley production in Germany. Zara (2010) concluded that hedging using the Strangle strategy results in a 22.06% lower volatility of the economic value of grape production compared to the economic value of grape production without hedging. Raucci *et al.* (2019) designed a weather derivative contract and evaluated hedging efficiency in the Brazilian soybean market. Their findings showed that the adoption of weather-based derivatives reduces the income volatility around 30%. Turvey (2001) also examined the economics and pricing of weather derivatives taking into account the Ontario market and rain and heat-based call and put options. In Bobriková (2016), we focused on weather derivatives and their application in agriculture. We presented options with the payoffs depending on temperature index HDD suitable for farmers affected by extremely cold or hot winter. Hedging strategies against unfavourable temperature conditions were created and an economic analysis was performed. Weather risk is of particularly great importance for the energy industry. Papers by Müller and Grandi (2000), Cui and Swishchuk (2015), and Matsumoto and Yamada (2021) analyzed various types of weather-related risks in the energy market.

Based on the above papers we can conclude that weather derivatives are considered to be effective if their application leads to lower volatility in the economic value of the output. There is no generally accepted criterion for measuring the effectiveness of weather derivatives. Most authors Ender and Zhang (2015), Zhou *et al.* (2018), and Raucci *et al.* (2019) analyze the variance and standard deviation to assess their effectiveness in reducing yield volatility.

In this paper, we study the role of weather derivatives in hedging against the impact of non-catastrophic weather conditions in agriculture. We analyse several weather variables, i.e., temperature, precipitation, and wind speed. Based on the partial findings, we calculate the Rainfall index and the premiums of call and put options with the payoff function depending on the rainfall. The Burn analysis is used in pricing of call and put options. The study of the role of weather derivatives in hedging is conducted in the Košice region of Slovakia. We also design hedging strategies and their substrategies that can stabilize the economic value of the agricultural production which is affected by the precipitation. Our findings can be useful to farmers who are exposed to the risk of an unfavourable increase in precipitation and its impact on their yields. In addition, the paper presents hedging effectiveness of the proposed strategies. Hedging strategies for farmers in Slovakia can support public policy aimed to increase global food security by mitigating the effects of catastrophic events. The issue of food security addressed from various perspectives including climate change is provided in the book by De Castro *et al.* (2012).

2. RESEARCH METHODOLOGY

The agricultural sector has high exposure to weather risks. For this reason, farmers are one of the main potential users of weather derivatives. Our aim is to design weather derivatives for risk management in agriculture and to evaluate the hedging efficiency against adverse weather conditions. Our research methodology consists of 3 steps. The first step is to find the best underlying weather index for agriculture using correlation analysis and to price the weather derivatives using the Burn analysis. In the second step, the weather derivatives are proposed and compared. Finally, the hedging efficiency of weather option strategies is examined and discussed.

The underlying index is one of the most important parameters of weather derivatives. Popular indices are temperature, wind speed, wind power, rainfall, hurricane, and humidity. Temperature related weather derivatives are the most frequent type on the market. Three indices are determined and used by temperature derivatives: Heating Degree Days (HDD), Cooling Degree Days (CDD) and Cumulative Average Temperature (CAT). These indices are the most favoured by the energy companies (Bemš and Aydin, 2021). Unlike the energy sector, where there is a presumption of a clear relationship between energy consumption and temperature, agriculture assumes a similar presumption of a relationship between production and some weather variables. Therefore, we decided to examine the relationship between several weather indices based on different weather factors and yields from agriculture products in a selected region. Previous studies (Turvey, 2001; Hess *et al.*, 2002; Musshof *et al.*, 2011; Alexandridis and Zapranis, 2013b; Ender and Zhang, 2015; Bobriková, 2016; Raucci *et al.*, 2019), have focussed on weather risk management using weather derivatives in agriculture. Taking into account their findings we adopt the following weather indices:

- temperature indices – CAT and CDD,
- rainfall index RAINFALL,
- wind speed index CAWS.

CAT (Alexandridis, 2012) is defined as:

$$CAT(t) = \sum_{i=1}^{t} T_i \tag{1}$$

- $CAT(t)$ is the cumulative average temperature for the period t,
- t is number of days.

According to Alaton (2002), the degree day index CDD is:

$$C_t = \sum_{i=1}^{t} CDD_i \tag{2}$$

- C_t is the cumulative for the period t,
- t is number of days,

where

$$CDD_i = max\{T_i - 18\ ;\ 0\} \tag{3}$$

- CDD_i is the Cooling Degree Days for the day i.

Rainfall index is expressed by the formula (Cramer, 2019):

$$Rainfall_t = \sum_{i=1}^{t} r_i \tag{4}$$

- $Rainfall_t$ is the rainfall index,
- r_i is the amount of precipitation for the day i.

CAWS is the sum of daily average wind speeds over a period of time and is given by Alexandridis (2012) as:

$$CAWS_t = \sum_{i=1}^{t} DAWS_i \tag{5}$$

- $CAWS_t$ is the wind speed index for the period t,
- $DAWS_i$ average wind speed for the day i.

If farmers want to ensure their yields by hedging with options, they must first pay the price in the form of an option premium. Since weather options are not traded on the market, their price must be determined

(Musshof *et al.*, 2011). Three parameters are needed to calculate the price – the strike value, the spot value of the index and the tick size. The spot value of the index is calculated for each year on the basis of historical data. The tick size is set at 1 Euro. We determined the strike values on the basis of the average and standard deviation of the annual Rainfall index:

$$K_1 = \frac{1}{N}\sum_{i=1}^{N} Rainfall_i - \frac{\sigma}{2} \tag{6}$$

$$K_2 = \frac{1}{N}\sum_{i=1}^{N} Rainfall_i \tag{7}$$

$$K_3 = \frac{1}{N}\sum_{i=1}^{N} Rainfall_i + \frac{\sigma}{2} \tag{8}$$

- k_1, k_2, k_3 are strike prices,
- σ is standard deviation of the underlying index during the period,
- $Rainfall_i$ is value of the underlying index in year i,
- N is number of years.

After determining the strike prices, we apply the pricing method Burn analysis. This method calculates the expected payoff of weather option as the average of the payoffs in the past during the period (Jewson, Brix, 2005; Benth and Benth, 2007). The expected payoff is defined by the equation:

$$Expected\ payoff = \frac{1}{n}\sum_{i=1}^{n} p_i \tag{9}$$

with payoff p_i in the year i and the call and put option premiums:

$$p_{ic} = max\{R_i - K;0\} * tick\ size\ for\ call\ option \tag{10}$$

$$p_{ip} = max\{K - R_i;0\} * tick\ size\ for\ put\ option \tag{11}$$

The symbol R_i refers to the rainfall index value in the year *i*. The symbol *K* is the strike index. The price of options can be calculated as a so-called fair premium using the Burn analysis. The term fair premium means a price at which the expected profit from an option for both parties is exactly zero. If risk premiums for the seller or buyer or transaction costs are not taken into account, the option price can simply be calculated as the expected payoff of the option. Since the option premium is paid at the time of the contract conlusion, the amounts expressed by (10) and (11) is discounted at the annual risk-free interest rate *r*. Based on the above, the price of options can be expressed as:

$$option\ premium = e^{-rT} * \frac{1}{n}\sum_{i=1}^{n} p_i \tag{12}$$

- r is risk-free interest rate,
- T is maturity period of an option.

The purpose of the proposed weather option hedging strategies is to hedge farmers' yields in the selected region against adverse weather condition during the year. We specify the contract maturity of 1 year. The proposed weather derivatives are options on the underlying weather index.

Generally, an option strategy involves the simultaneous combination of two or more option positions (Long Call, Short Call, Long Put, and Short Put). A call option gives the holder (buyer)/writer (seller) the right to buy/the obligation to sell an underlying weather index at a fixed strike price. A put option gives the buyer/seller the right to buy/sell the obligation to buy an underlying weather index at a fixed strike price. The buyer of an option has to pay an initial sum of money called the premium to the seller of the contract. Options may be combined, by means of which new forms and attractive investment opportunities are created. Option hedging strategies are presented in papers by Rusnáková (2015), Timková (2018) and Bobriková (2021).

Option hedging strategies designed and discussed in this paper and the characteristics of these strategies are listed in Table 1.

The selection of a suitable option hedging strategy is a systematic process based on the farmer's attitude to risk (high/neutral/low risk aversion) and expected payoff. Each of the strategies has strengths and weaknesses, which will be discussed in the results.

Hedge effectiveness of strategies is also investigated. Weather derivatives are considered effective if their application leads to reducing yield volatility, i.e., decreasing the uncertainty of future cashflows. We use the most common measure of volatility, i.e., the variation coef-

Tab. 1. Option strategies and characteristics.

	Volatility	Risk
Long Call	bulish	low
Long Straddle	neutral	low
Long Strangle	neutral	low

ficient and standard deviation. Firstly, we express the profits and losses in thousands of EUR from the hedging option strategies over the years 2010-2019. Subsequently, we create scenarios of yield development by adding these profits and losses to the annual yields of crops.

3. RESULTS

3.1. Data

The study was conducted in the Košice region of Slovakia. This region was chosen due to its high agricultural production. Kosice region with an area of 6 754.3 km^2 is located in the southeast of the Slovak Republic and occupies 13.8% of its territory. Agricultural land occupies 333 000 ha, which is almost half regional area; more than three-fifths of it is arable land and one third is permanent grassland and meadow (Statistical Office of the Slovak Republic, c2022).

Data were drawn from the European Climate Assessment & Dataset (ECA&D) database and the database of the Statistical Office of the Slovak Republic (DATAcube). This study analyses the impact of weather variables on crop yields using weather data from the Košice-airport meteorological station over the period 1980-2020 and annual yields from agricultural products in Košice region over the period 2010-2019. The weather dataset set consists of historical daily minimum and maximum temperature, precipitation, and wind speed.

3.2. Underlying weather indices and pricing of weather options

We analysed the development of the indices CAT, CDD, RAINFALL and CAWS. Basic statistical characteristics are in Table 2.

We performed a correlation analysis between selected weather indices and yields from agricultural products in the Košice region for the period 2010-2019. The correlation matrix is presented in Table 3. The results show that the Rainfall index has the highest correlation with yields. The correlation coefficient of -0.47 means a slightly negative correlation. The second highest correlation is the CAWS index with a correlation coefficient of 0.42, which indicates a slightly positive correlation. The CAT and CDD indices show only a weak correlation with the yields.

Based on the above analysis, we can say that the most suitable underlying index for the proposed weather derivatives for farmers in the Košice region is the Rainfall index. Therefore, we will focus on the valuation of weather derivatives based on the underlying Rainfall index. We use the Burn method in pricing. Rainfall index development from 01/01/1980 to 31/12/2020 is shown in Figure 1.

The payouts and average payouts of the proposed call and put options during the analysed period can be provided on request. We calculated premiums of call and put oprions with the time to maturity 1 year. The premiums are shown in Table 4.

3.3. Design of hedging strategies using weather options

In agriculture, extreme weather conditions (e.g., both too little and too much rainfall) cause falls in yield.

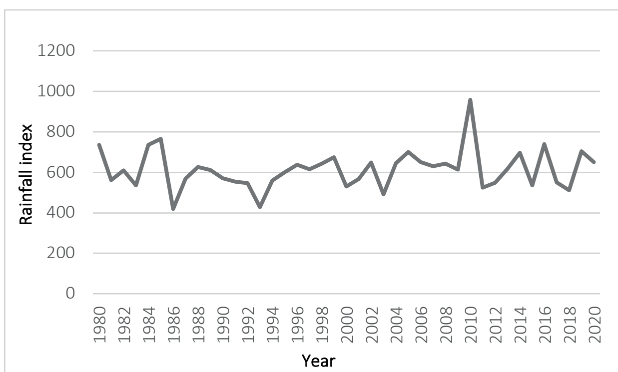
Tab. 2. Basis statistical characteristics of indices.

	CAT	CDD	RAINFALL	CAWS
Average	3843	2132	639	1153
Median	3742	2104	583	1162
Standard deviation	234	139	140	69
Dispersion	54822	19196	19633	4730
Margin	688	505	447	224
Minimum	3508	1960	512	1029
Maximum	4196	2466	959	1253
Variation coefficient	0.06	0.06	0.22	0.06

Tab. 3. Correlation matrix of weather indices and yields in agriculture.

	CAT	GDD	RAINFALL	CAWS	Yields
CAT	1				
GDD	0.69	1			
Rainfall	-0.28	-0.54	1		
CAWS	0.08	0.38	-0.26	1	
Yields	0.24	0.28	-0.47	0.42	1

Fig. 1. Graph of the Rainfall index development.



Tab. 4. Call and put option premiums.

Premium of Call option	Strike price based on Rainfall index	Premium of Put option
62.90	565.3	14.90
34.99	613.6	34.99
18.17	662.0	66.17

Tab. 5. Hedged scenarios by Long Call strategy.

Rainfall index range	Unhedged index value	Payoff from strategy	Hedged index value
R_T<K	-R_T	-c_L	-R_T -c_L
R_T≥K	-R_T	R_T-K- c_L	-K-c_L

Tab. 6. Hedged scenarios by Long Call strategy.

Rainfall index range	Unhedged index value	Payoff from strategy	Hedged index value
R_T<565.3	-R_T	-62.9	-R_T -62.9
R_T≥565,3	-R_T	R_T-565.3 -62.9	-628.2

Thus, the combination of a put and a call option based on the same underlying index can be appropriate (Berg *et al.*, 2006). Our aim is to design weather option hedging strategies using call and put options on the underlying Rainfall index against adverse weather conditions, specifically against excessive rainfall during the year.

The first strategy which can be used in the price risk management against excessive rainfall is Long Call strategy. We assume that the actual Rainfall index value is R_0. The call option on the rainfall index will attract a farmer whose profits are affected by the high rainfall index values in the future R_T. Long Call option on Rainfall index is the right to buy the rainfall index value for a fixed strike price K at maturity time T. The future payoff for every scenario is given in Table 5. Two variants of the scenario can occur at the maturity of an option. If the Rainfall index value at maturity date T is below the strike price K, then the farmer will lose the option premium c_L which is the cost of weather risk management. If the Rainfall index value at maturity date is above the strike price, then the farmer will obtain the payoff of (R_T -K-c_B).

Strategy 1: Long Call with the strike index value = 565.3 a premium = 62.9. The payoffs from this strategy and hedged index values are listed in Table 6.

Table 7 illustrates hedged index value and profit/loss from hedging strategy as the difference between

Tab. 7. Hedged rainfall index value by Long Call strategy.

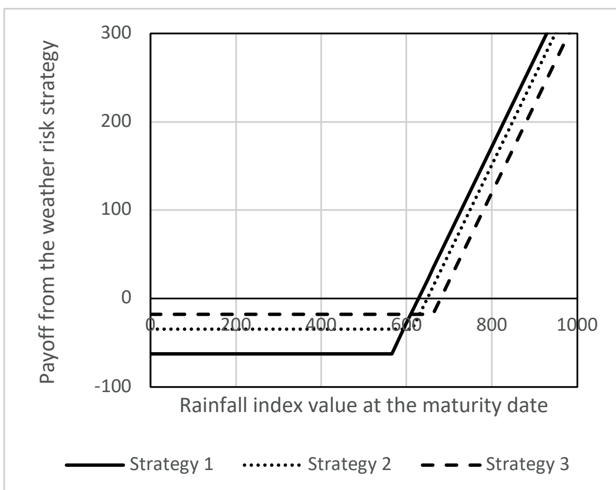
Rainfall index range	Hedged index value	Profit of hedging		Loss of hedging	
		Min	Max	Min	Max
R_T<565.3	-R_T-62.9	–	–	62.9	62.9
565.3≤R_T≥628.2	-628.2	–	–	0	62.9
628.2≤R_T	-628.2	0	∞	–	–

the hedged rainfall index value and unhedged rainfall index value at maturity date T. If the difference is positive (more than 0), the hedged position is better than the unhedged position.

We created Strategy 2: Long Call with the strike index value K = 613.6 a premium = 34.99 € and Strategy 3: Long Call with the strike index value K = 662 a premium = 18.17 €. The comparison of payoffs from Strategies 1, 2 and 3 at various development of Rainfall index value at the maturity date is shown in Figure 2.

Using options with various strike index value, the hedging profit sensitivity could be examined. For an option buyer, the premium represents the maximum cost that can be lost. If the strike index value is higher, lower costs are needed for the buying of an option and therefore the profit from the strategy is lower. The profit is unlimited. The loss is limited by the option premium. It can be seen, but also be calculated exactly using payoffs from strategies that the weather risk strategy 1 ensures the highest profit if the rainfall index value at the maturity date is higher than 593.21. The cost of this benefit is the highest option premium. This hedging variant is available to the farmer with a higher degree

Fig. 2. Comparison of payoffs from the weather risk strategy Long Call.



Tab. 8. Hedged scenarios by Long Straddle strategy.

Raifall index range	Unhedged index value	Payoff from strategy	Hedged index value
R_T<K	-R_T	-R_T +K-c_L-p_L	-2R_T -K-c_L-p_L
R_T≥K	-R_T	R_T -K-c_L-p_L	-K-c_L-p_L

Tab. 9. Long Straddle strategies.

	Strike price	Premium of Long Put	Premium of Long Call
Strategy 4	565.3	14.9	6.9
Strategy 5	613.6	34.99	34.99
Strategy 6	662	66.17	18.17

of risk aversion. A low-risk-aversion farmer will prefer the hedging strategy 3. If the rainfall index value at the maturity date is lower than 593.21 the loss of hedging strategy 3 is the lowest. The weather risk strategy 2 is the most suitable hedging strategy for the farmer with a neutral risk aversion.

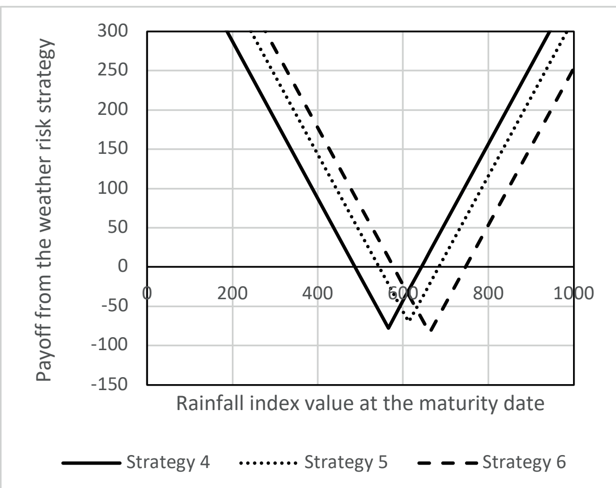
Long Straddle strategy can also be a weather risk management tool. It is formed by Long put option position with a strike price K and option premium p_L and Long call option with the same strike price K and option premium c_L. The payoff for every scenario is indicated in Table 8.

3 substrategies of Long Straddle strategy are given in Table 9 and their comparison is shown in Figure 3.

We can deduce following conclusions. The Long Straddle Strategy is the most expensive of the analysed hedging strategies. It can be seen, but also calculated, that the Long Straddle strategy 4 ensures the highest payoff or the lowest loss if the rainfall index value at the maturity date is higher than 610.38. On the other hand, strategy 4 has the most loss if the rainfall index value at the maturity date is lower than 593.36. It is suitable for a farmer who expects lots of rainfall.

Long Straddle strategy 6 ensures lower payoff in the case of high Rainfall index values but higher payoff at low Rainfall index value. Strategy 5 is for the neutral risk aversion farmers.

Fig. 3. Comparison of payoffs from the weather risk strategy Long Straddle.



Tab. 10. Hedged scenarios by Long Strangle strategy.

Rainfall index range	Unhedged index value	Payoff from strategy	Hedged index value
R_T<K_1	-R_T	-R_T + K_1-p_L-c_L	-2R_T + K_1-p_L-c_L
K_1< R_T≤ K_2	-R_T	-p_L-c_L	-R_T -p_L-c_L
R_T≥ K_2	-R_T	R_T – K_2-p_L-c_L	– K_2-p_L-c_L

Tab. 11. Long Strangle strategies.

	Strike price of Long Put	Premium of Long Put	Strike price of Long Call	Premium of Long Call
Strategy 7	565.3	14.9	613.6	34.99
Strategy 8	613.6	34.99	662	18.17
Strategy 9	565.3	14.9	662	18.17

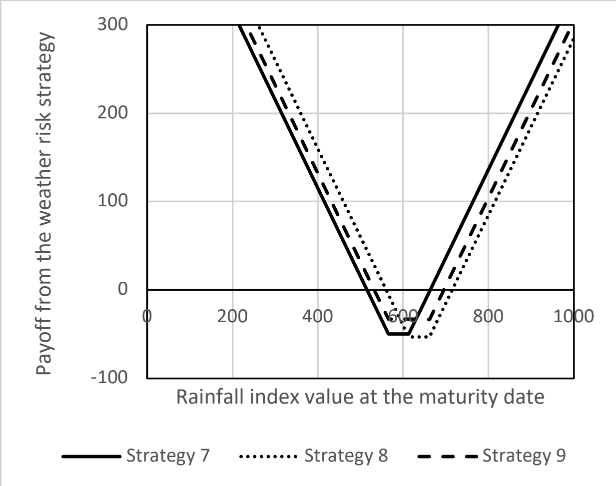
The Long Strangle option strategy, like the Long Straddle, provides the opportunity to hedge against high and low values. It is created by buying n call options with a lower strike price K_1 and buying n put options on the same underlying index with a higher strike price K_2. This strategy is suitable for farmers whose yields are negatively affected by high or low underlying index values. The payoff of Long Strangle strategy is given in Table 10.

Parameters of proposed Long Strangle substrategies are in the Table 11.

The comparison of option strategies 7, 8 and 9 is shown in Figure 4. We can state that:

- Strategies 7 and 9 have different strike index values of Long Call option. The higher the strike price of Long Call, the lower the payoff in the case of index growth, i.e., more precipitation. On the other hand, the higher the strike price of Long Call, the higher the payoff in the case of index fall.
- Strategies 8 and 9 have different strike index values of Long Put option. The lower the strike price of Long Put, the higher the payoff in the case of index growth. The lower the strike price of Long Put, the lower the payoff in the case of index fall.

Fig. 4. Comparison of payoffs from the weather risk strategy Long Strangle.



- Strategy 7 ensures the highest profit compared to other strategies in the case of high values of the Rainfall index (more than 630.64), but on the other hand, the lowest profit in the case of low values of the Rainfall index. Strategy 8 is the best if the index value is lower than 593.51 at the maturity date. Strategy 8 is appropriate for farmers who want to hedge against too little precipitation. Strategy 9 generates medium rainfall index values. Therefore, it is the potential strategy for both too low and too high rainfall expectations.

3.4. Hedging effectiveness

Using ex post analysis, we examine the hedging effectiveness. Is it possible with the application of the proposed hedging strategies to reduce the volatility of farmers' yields? We measured the hedging efficiency similar to Spaulding *et al.* (2003) and Zara (2010) using the variation coefficient.

We calculate the profits and losses in thousands of EUR from the option hedging strategies within the years 2010-2019. The hedge scenarious represent the development of yields with hedging strategies application. The profits/losses from the hedging strategy are shown in Table 12 and hedged yields are presented in Table 13.

By comparing the volatility of unhedged yields with that of hedged yields with application of strategies S1-S9, we found that the volatility of yields measured by variation coefficient decreased (Table 14). Based on the analysis, the most effective strategy is strategy 4. The findings show that application of this strategy results in lower volatility of the yield by 15.66% compared to the value of the yields without the weather option strategy application. Strategy 6, which reduced yield volatility by 9.46%, reaches the worst results. Figure 5 shows the development of yields with (gray line) and without (black line) weather application for strategy 4.

Based on the hedge effectiveness analysis, it can be conluded that application of the proposed hedging strategies reduced the volatility of yields by 9.46 to 15.66%. Our findings confirmed the hypothesis that the application of weather option strategies reduced the farmers' yield volatility in agriculture. Results suggest that weather derivatives can be considered as appropriate tools to hedge against adverse weather conditions.

4. CONCLUSION

Weather derivatives are the new non-catastrophic weather risk management tool. Although they were originally developed in the United States for the energy industry, their application is now possible in many other

Tab. 12. Profit/losses in thous. EUR from hedging strategies S1-S9.

	S1	S2	S3	S4	S5	S6	S7	S8	S9
2010	49 605	46 547	41 810	47 372	41 297	31 883	44 312	36 561	39 575
2011	-9 435	-5 249	-2 726	-5 489	2 926	8 032	-1 304	5 451	1 219
2012	-9 435	-5 249	-2 726	-9 209	-793	4 313	-5 024	1 731	-2 500
2013	-1 785	-4 843	-2 726	-4 018	-10 093	-5 798	-7 078	-7 974	4 961
2014	10 719	7 660	2 923	8 485	2 410	-7 004	5 425	-2 325	688
2015	-9 435	-5 249	-2 726	-7 352	1 063	6 169	-3 167	3 588	-644
2016	16 744	13 685	8 948	14 510	8 435	-979	11 450	3 700	6 713
2017	-9 435	-5 249	-2 726	-9 464	-1 049	4 057	-5 279	1 476	-2 756
2018	-9 435	-5 249	-2 726	-3 643	4 772	9 878	542	7 296	3 065
2019	11 325	8 266	3 529	9 091	3 016	-6 398	6 031	-1 719	1 294

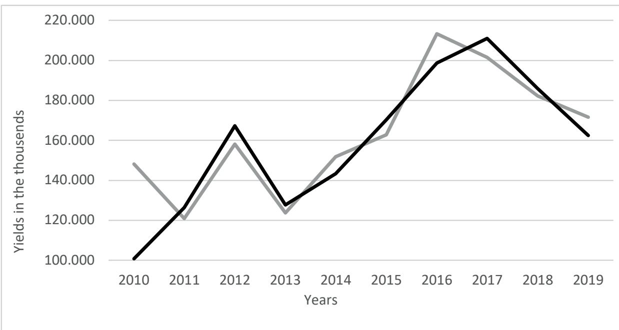
Tab. 13. Unhedged yields and hedged yields by hedging strategies 1-9.

	Yields (Y)	Y+ S1	Y+ S2	Y+ S3	Y+ S4	Y+ S5	Y+ S6	Y+ S7	Y+ S8	Y+ S9
2010	100 811	150 416	147 357	142 620	148 182	142 107	132 693	145 122	137 372	140 385
2011	126 417	116 982	121 169	123 692	120 929	129 344	134 450	125 114	131 868	127 637
2012	167 276	157 841	162 028	164 551	158 068	166 483	171 589	162 253	169 007	164 776
2013	127 677	125 892	122 833	124 951	123 658	117 583	121 879	120 598	119 703	122 716
2014	143 270	153 989	150 930	146 193	151 755	145 680	136 266	148 695	140 945	143 958
2015	170 228	160 793	164 979	167 502	162 876	171 291	176 397	167 061	173 815	169 584
2016	198 739	215 483	212 425	207 688	213 250	207 175	197 761	210 190	202 439	205 453
2017	210 921	201 486	205 673	208 196	201 458	209 873	214 979	205 643	212 397	208 166
2018	185 910	176 475	180 662	183 185	182 267	190 682	195 788	186 452	193 206	188 975
2019	162 466	173 791	170 733	165 996	171 558	165 483	156 069	168 498	160 747	163 761

Tab. 14. Decrease of the variation coefficient by application of hedging strategies in %.

	S1	S2	S3	S4	S5	S6	S7	S8	S9
Variation coefficient (in %)	*-14.78*	*-14.62*	*-15.53*	*-15.66*	*-12.37*	*-9.46*	*-14.64*	*-11.50*	*-19.12*

Fig. 5. Graph of the yield development with and without weather application: the case of hedging strategy 4 for the period 2010-2019.



sectors, including agriculture. Agriculture and the global food supply are susceptible to the impacts of climate change. Slovakian agriculture and food supply are no exception to this. The use of weather derivatives as risk management tools in Slovak agribusiness is non-existent. Thus, this paper has contributed to filling a gap in the literature with the aim of improving the weather risk management activities of producers. The methodology of this research can also be helpful for weather derivative hedging in other regions.

In the theoretical part of the paper, we focused on introduction to the weather derivatives. We characterized the main parameters, which include: type of contract, contract period, underlying index etc. The main part provided the analysis of hedging using weather derivatives in agriculture and the design of weather derivatives for hedging of farmers in the Košice region. We used a correlation analysis, in which we examined the relationship between individual weather indices and farmers' yields. We found that the most appropriate underlying index is the Rainfall index. Call and put options were evaluated based on the underlying Rainfall index using the Burn method.

Subsequently, using these options, we proposed 9 strategies, which we analyzed and compared. Based on the results of the analysis and comparison we formulated recommendations for farmers in terms of their use of hedging in agriculture in the Košice region. Based on a review of expert studies, we performed an ex-post analysis of effectiveness of weather hedging in agriculture, which was measured by the relative reduction in yield volatility. By comparing the volatility of hedged yield development with the unhedged yield, we found that producers were able to reduce the climate risk with a significant fall in yield variation using Rainfall index hedging option strategies. The results show that the proposed strategies are effective in weather risk management in agriculture. The most effective strategy is strategy 4. Adoption of the weather derivatives reduced the yield volatility of producers (expressed by the variation coefficient) by up to 15.66%. We can confirm that the weather derivatives offer unique risk management instruments for agricultural producers.

Further research can provide the hedging efficiency of mixed-based weather derivatives that are based on several weather variables, e.g., temperature and rainfall. Moreover, an important issue is to investigate the potential benefits and limitations of weather derivatives for particular crops and areas. Finally, other climate models can suggest a double seasonal analysis for meteorological variables.

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Research article

The economic value of ecosystem services of irrigation: a choice experiment for the monetary evaluation of irrigation canals and *fontanili* in Lombardy

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Abstract. The Water Framework Directive (WFD) has introduced economic principles for water resource management, including the environmental cost recovery on the basis of the polluter pays principle (PPP). Agriculture, as a potential driver of pressures on water bodies, can produce environmental costs. However, the use of water in agriculture can produce ecosystem services (ES), especially through the aquatic systems of the traditional irrigation agro-ecosystem. This work presents a case study of monetary estimation of some ES of aquatic ecosystems linked to irrigation, i.e. irrigation canals and fontanili in Lombardy (Italy). Through the choice experiment method, we obtained positive values of willingness to pay for the highest levels of ES analysed. This has an implication in the context of the economic analysis of water uses and the decision-making process within the interventions planning of irrigation efficiency improvement.

Keywords: irrigation, water framework directive, ecosystem services, choice experiment, economic analysis.
JEL codes: Q25, Q26, Q51, Q57.

HIGHLIGHTS

- The Willingness to Pay for the ecosystem services of traditional aquatic systems linked with irrigation is estimated through the choice experiment method
- Traditional irrigation network has an environmental and cultural value monetarily measurable
- Water saving measures should consider any loss of value of ecosystem services of aquatic systems linked with irrigation
- Water Framework Directive implementation should take into account territorial specificities

1. INTRODUCTION

To date, macroeconomic decision-making is still largely driven by information derived from the System of National Accounts (SNA). The most relevant indicator of the SNA is the Gross Domestic Product (GDP), which, although frequently used as an indicator of well-being, does not indicate the satisfaction of our complex society (Stiglitz, 2009). To fill this gap, several efforts have been made in recent years to implement accounting systems based on the natural capital approach. The Natural Capital Approach was introduced by Costanza and Daly in 1992 and indicates the stock of natural resources that produce wealth. The term Natural Capital refers to the analogy with the economic system, in which capital represents the stock that produces value flows. From the interaction within the stocks of Natural Capital derives the flow of ES, defined as the multiple benefits people obtain from ecosystems (MEEA). ES should be quantified in monetary terms to internalize so-called externalities, which generate allocation inefficiencies due to market failures. Environmental goods and services, being not rival and not excludable, generate costs and benefits for the community, which are added to the cost and private marginal benefit. This causes excessive supply (in the case of negative externalities) and, on the contrary, a modest production of public goods and services (in the case of positive externalities). Payments for ecosystem services (PES) play a fundamental role in encouraging the production of ES. A PES scheme is defined as a voluntary agreement between at least one "seller" of an environmental good/service and a "buyer" (Wunder, 2005, 2015) and they were introduced in Italy with l. 221/2015.

Regarding ES related to water resources and aquatic environments, monetary quantification is relevant for the implementation of directive 60/2000/EC (Water Framework Directive, WFD) economic principles. Art. 9 relates to the polluter/user pays principle (PPP) and adequate recovery of water services costs. This also includes environmental and resource costs, to be achieved through an appropriate pricing policy. Therefore, the legislation requires the quantification of the environmental and resource costs and the quota of contribution of water use sectors based on the economic analysis to be implemented in the River Basin District Management Plans (RBDMPs).

The WFD promotes the use of economic instruments, both in terms of cost recovery levers and requiring the monetary quantification of physical processes, such as environmental pressures and benefits. This involves some efforts to deepen knowledge of the economic and environmental aspects related to the use of water, including agriculture, which has many interactions with ecosystems.

The water cost recovery principle has been clarified by the European Common Implementation Strategy Working Group on Water and Economics (WATECO), which drafted a guide for the Assessment of Environmental and Resource Costs in the WFD. This document points out the breakdown of the total cost of water use into three main components: i) financial cost (including investment and operation and maintenance cost); ii) resource cost, i.e. the cost generated in scarcity conditions if an alternative use would generate a higher economic value; iii) environmental cost, which is the cost to recover the damage produced by pressures on the water resource. The WATECO guide also clarifies the process of internalization of environmental cost; in particular, environmental costs can be internalized if the measures aimed to compensate the damage are implemented and financed by the user/polluter. This can be considered an application of the cost-based methods for ES valuation (in particular the replacement cost). In addition to this cost-based approach, the Commission also proposes a benefit-based approach, which estimates the loss of well-being due to environmental damage or increased welfare if environmental damage is avoided, calculated through the willingness to pay by the community for the implementation of measures.

The information provided by WATECO guided the drafting of the Italian National Guidelines to determine environmental and resource costs resulting from different water uses (ministerial decree n. 39 of February 24th, 2015, issued by the Ministry of Environment) and the drafting of the Operational and Methodological Manual for the Implementation of Economic Analysis (directorial decree 574/STA of 6 December 2018).

In the context of economic analysis under WFD, it is important to consider the negative externalities of irrigation, which are due to withdrawals and water pollution through fertilizer and pesticides use (Racchetti *et al.*, 2019; Bouwer, 1987; Chen *et al.*, 2010)

However, it is also important to consider the positive externalities of agricultural water use. As recognized by the National Guidelines on water and resource cost, some aquatic systems, including those related to irrigation, can produce ES, also in the form of positive externalities (Natali, Branca, 2020). The *Manual* indicates including positive externalities of water uses in the socio-economic description of basin district and the context of quantification of water cost recovery contribution through measures of the Programme of Measures (PoMs). In particular, positive externalities directly affecting water bodies, replacing measures for the recovery of environmental damage, are a proxy of environmental cost. These can be assessed with both a cost-based approach and a benefit-based approach. Therefore, the quantification of ES in monetary terms is also useful for the proper implementation of economic analysis. The value of the benefits should be subtracted from the cost to the agricultural sector (according to the benefit-based approach) or be considered as an internalized environmental cost (cost-based approach).

The theme of ES of irrigation is often in contrast with the theme of irrigation efficiency, which plays an important role in the PoM and Article 9 of WFD, which requires the presence of water pricing policies encouraging efficient water use. In particular, the increase in traditional irrigation efficiency may reduce return flow (Kendy, Bredehoeft, 2006). The ecological structures of an irrigated agro-ecosystem capable of producing ES are mainly typical of traditional systems with a low level of hydraulic and irrigation efficiency. For example, uncoated irrigation ditches cause several leaks by infiltration and evaporation; furthermore, traditional irrigation practices, such as flooding and furrow irrigation, require large volumes of water, of which only a small part meets the needs of crops. Part of the trade-off between efficiency and ES of irrigation is developed in the conceptualization of effective water use, which takes into account the return flow into the aquifer available for "downstream" uses (Keller *et al.* 1996). Consequently, a system evaluated as poorly efficient at the field scale can be efficient at the basin scale, thanks to the return flows in the aquifer. This may make interventions for improving irrigation efficiency on a small scale because of increased volumes used at the basin scale (Grafton *et al.*, 2018; Kendy, Bredehoeft, 2006; Ward, Pulido-Velazquez, 2008). Water flow infiltrated into groundwater upstream and re-emerged downstream can be useful for other productive uses or can feed wetlands (Peck, Lovvorn, 2001).

The trade-off between efficiency and ES of aquifer recharge can be solved considering the "environmental use" of water in the context of water use efficiency as proposed by Brown *et al.* (2012), defined as the portion of water applied for environmental purposes, including water to produce and/or maintain wetlands, riparian or terrestrial habitats.

In recent years, measures have been taken in Italy to modernize irrigation networks, through conversion from open canal systems to pressure pipelines, as well as measures to convert irrigation techniques to more efficient systems, such as drip and sprinkler irrigation. Although these measures promote water saving, with environmental benefits in terms of protecting the quantitative status of water bodies affected by withdrawals, they can lead to alterations of some environmental functions of the agricultural landscape, especially in those strongly linked to the presence of irrigated water. Works linked to irrigation and the irrigated fields have created balances in terms of interchanges between water flows of natural and artificial freshwater systems and between underground and surface water circulation. They have also shaped the territory, characterizing it from an aesthetic-landscape point of view, providing the conditions for the formation and maintenance of habitats, supporting animal and plant biodiversity.

ES of the irrigated agroecosystem should be valued in monetary terms. This is also useful to take into account changes in their value as a result of policies for water saving, including interventions to increase irrigation efficiency.

Ultimately, the monetary quantification of ES is useful in two areas identified in the conceptual framework of this study: i) contribution to the quantification of the share of environmental cost to be deducted from the total cost to be borne by the agricultural sector in the context of economic analysis under WFD; ii) contribution to the analysis of possible environmental costs generated (paradoxically) by savings policies in agriculture.

This study aims to evaluate in monetary terms some ES of specific aquatic ecosystems linked to irrigation though choice experiment method, frequently used for monetary estimation ES, including aquatic ES (Khan *et al.*, 2019; Doherty *et al.*, 2014). This study differs from the analyses previously produced, because it applies the choice experiment to artificial water bodies linked to the irrigated agro-ecosystem, partly following the approach of other authors (Zucaro *et al.*, 2020; Aizaki *et al.*, 2006; Hasund *et al.*, 2010; Sayadi *et al.*, 2009).

With respect to the latter, this study identifies two specific aquatic systems as a source of ES, following a cascade approach (Haines-Young, Potschin, 2010). Furthermore, the monetary quantification of positive externalities is within the context of irrigation efficiency, which in cases such as that of the study area could paradoxically decrease the value of the flow of ES. Finally, political implications are considered within the context of economic analysis under the WFD.

2. STUDY AREA

Lombardy is historically rich in water, although in recent years it has faced frequent drought events. Water is traditionally derived by gravity from surface water streams; only in the last century lifting from surface water streams and extraction from groundwater have spread.

The territory was shaped by the extensive and dense canals network originating from the main rivers. Irrigation strongly characterizes the territory both of the valley, where the landscape is drawn by canals, irrigation ditches, and buildings of hydraulic engineering, and of the upstream area, though lakes control structures. All these works make the Lombard territory a symbol of the union between artificiality and naturalness.

A peculiarity of the Lombard territory is represented by the *fontanili*, which are springs of human origin, historically used as a source of water supply for irrigation.

The *fontanile* is a water intake in the non-emerging aquifer created to raise, collect, direct and use groundwater for irrigation purposes. It differs from the natural resurgence, which refers to the spontaneous surfacing. The *fontanili* were used for the irrigation of *marcite* (type of permanent grassland), which made it possible to have fresh fodder even during the winter season, and therefore to increase livestock production. The *fontanile* comprises two main parts: the head and the shaft. The head consists of an excavation in the ground to intercept the groundwater. The shaft consists of a ditch dug, starting from the head, to drain the surface water towards the fields or to irrigation canals. The *fontanili* are of great interest from the point of view of nature and landscape, so they are recorded at the regional level. In addition to the original irrigation function, they also perform a cultural, recreational and ecological function (Bischetti *et al*., 2012).

The *fontanili* are biodiversity hotspots; the temperature of the water remains relatively constant throughout the year, which ensures the maintenance of a cool summer microclimate. At the same time, it prevents the freezing of water during winter, favouring the development of vegetation even in colder periods. Waters of *fontanili* are crystalline, thanks to the purification processes that take place underground. The riparian strips around the *fontanili* offer niches ideal for nesting birds and represent important habitats for many reptiles and mammals. The feeding of *fontanili* is strictly dependent on the interrelations between surface and underground flow, in which irrigation plays a fundamental role. This is due to the existence, in the Lombardy plain, of two separate areas from the geological and pedological point of view: i) the area of the high plain, whose soil, being composed of pebbles and gravel, is highly permeable; ii) the low plain, in which the soils are formed by more impermeable materials. The volumes of water supply in the upper plain area, with both rainfall and irrigation, easily percolate into the subsoil, reducing the amount of water useful for crops. These volumes return to the surface, giving rise to spring phenomena where the coarse lithologies (high plain) meet the impermeable and fine-grained substrates, typical of the low plain. Springs and *fontanili* create a "band", the so-called "Band of Resurgence" that crosses the Lombard territory longitudinally, as well as the neighbouring regions. Therefore, the percolation processes of uncoated canals and fields irrigated through submersion and flow irrigation in the upstream area ensures the supply of *fontanili* in the downstream area (Gandolfi *et al*., 2006; Balderacchi *et al*., 2016).

3. MATERIALS AND METHODS

3.1. The ecological structures selection

For the analysis of the case study, sources of ES were selected focusing attention on ES linked to percolation processes, also given its importance in the study area in relation to the feeding of *fontanili* and natural springs. Considering the description of the study area, the agro-ecological structures able to favour these processes are irrigation canals on land and irrigated fields. Some information on the ES of irrigation canals can be derived from the literature, although these can refer to different territorial contexts.

As regards the landscape value, Hasund *et al.* (2010) conducted a choice experiment to estimate the WTP for public goods of the agricultural landscape in Sweden, including among the attributes the presence of canals, whose estimated value amounted to € 9.54 / year.

Regarding the biodiversity support, although these anthropogenic systems are lower quality habitats than larger and more stable water bodies (such as rivers and lakes), in a context where natural systems are rare, they can serve as complementary habitats (Herzon, 2007; Rolke *et al*., 2018). In many cases, irrigation canals host several communities of invertebrates (Verdonschot *et al*., 2011; Hill *et al*., 2016), fish and amphibians (Piha *et al*., 2007; Romano *et al*., 2014; Aspe *et al*., 2016), birds (Fasola, 1986; Loòpez-Pomares *et al*., 2015) and mammals (Defra, 2002).

Irrigation promotes the protection of biodiversity also through a contribution to the feeding of wetlands. In the national context, the contribution of irrigation to the feeding of *fontanili* in Northern Italy was highlighted (Balderacchi *et al*., 2016; Gandolfi *et al*., 2006) (see par. 3.2). Peck and Lovvorn (2001) estimated that the contribution of irrigation in terms of inflows in 74 wetlands being studied in North West America is equal to 65%.

Several studies have also been conducted to analyze the contribution of transport losses from uncoated canals to the aquifer recharge due to percolation processes. These, in fact, can generate positive effects if they are "beneficial losses", i.e. losses that are reused or recycled for other beneficial uses. Dagés *et al.* (2020) report the results of some measurements on a study area characterized by a dense canal network in a basin in the south of France in the autumn period. The results show a contribution of concentrated recharge from irrigation canals equal to 40-50% of the total recharge. Sèraphin *et al.* (2016) show that, in the study area considered (a basin in the south of France), the contribution of irrigation to the recharge of aquifers varies between 9% and 69% and is due to specific irrigation practices and the presence of uncoated canals. Through aquifer recharge, losses of irrigation canals feed wetlands, in particular during spring. Aquifer recharge presents problems related to the qualitative pressure on aquifers due to the percolation of polluting inputs. However, as regards the canals on land, this problem is limited, since the water pollution caused by runoff from the irrigated fields is mitigated by riverbed and riparian vegetation (Castaldelli *et al.*, 2015).

Therefore, for the case study analysis, vegetated uncoated irrigation canals were chosen. Thanks to the aquifer recharge ES, these are fundamental for the replenishment of *fontanili*, thus indirectly generating additional ES. In fact, *fontanili*, like springs, are Groundwater Dependent Ecosystem (GDE), so the presence of water in the aquifer, in turn, dependent on the exchanges between water flow processes in the Lombard high and low plain, is fundamental for their maintenance (Balderacchi *et al.*, 2016). Hence, also *fontanili* were chosen for the case study, both for their indirect services of the canals, and as another example of an aquatic system linked to irrigation capable of providing ES.

The ES choice was made considering benefits dependent on the water regime and, therefore, subject to changes caused by efficiency measures.

3.2. Method

The Choice experiment method (CE) was used to estimate the monetary value of the ES under analysis. This method has been used to estimate benefits of irrigation (Zucaro *et al.*, 2020; Hasund, Lagerkvist, 2011). Like contingent valuation, CE is based on the collection and analysis of questionnaires (Mazzanti, Montini, 2001). Compared to the contingent valuation, it can estimate the individual benefits of the environmental good characteristics, based on the assumption that any economic good can be represented by its characteristics ("attributes") and the different levels at which they occur. The purpose of the CE is to estimate the value of the changes in the demand of individuals for the different goods generated by different characteristics. This assumption is based on the economic theory of Lancaster (1966), which affirms the possibility of splitting the utility of the consumer in the utilities deriving from the individual attributes of an asset. From this derives the problem related to the impossibility of capturing the entire value of an environmental good, as there are elements of a subjective nature difficult to identify and quantify. The CE solves this problem in part, as the method is based on the stochastic utility approach (McFadden, 1973), which allows disaggregating the overall utility into two components, a deterministic and an error component.

The first step of the CE is the choice of attributes of the good under study. For each attribute, a vector of levels must be defined. Combinations of levels and attributes are the options respondents are asked to choose from. Using some models, it is possible to identify the weight that respondents place on the presented attribute with a certain level. This weight corresponds to the coefficients of the logit function that estimates the probability of individuals choosing a given alternative. For the estimation of coefficient, Random Parameter Logit Model (RPL) has been used, which, unlike the multinomial logit model, allows heterogeneity to be captured, as coefficients are indexed for each individual.

3.3. Data collection, survey structure and experiment design

To estimate the monetary value of the selected ES, a survey based on questionnaires sent electronically to a sample of Lombard citizens was conducted in the period March-December 2021. The non-probability sample, consisting of 222 units, was obtained through the "snowball" method, selecting units belonging to different contexts (schools, universities, reclamation consortia, social networks) having the characteristic of interest (being resident and/or domiciled in Lombardy) and asking them to indicate other units belonging to the same characteristic.

Attributes and levels used for the design of the experiment are listed in Table 1. For the attribution of levels, we investigated scenarios due to alterations in the water regime canals and *fontanili*. For biodiversity, we obtained information on the animal and plant species present in different conditions of water regime of the *fontanili* (Bischetti *et al.*, 2012). For canals, no information was found in relation to plant biodiversity; therefore, only the presence of aquatic animal species was considered.

Tab. 1. Attributes and levels used for the choice experiment.

Aquatic system	Attributes	Levels
Irrigation canals	Landscape	Semi-dry canal; canal at full capacity
	Animal biodiversity	High (presence of aquatic species), medium (aquatic species decrease); low
	Aquifer recharge	High; medium; absent
	Recreational activities	Possible; not possible
Fontanili	Landscape	Presence of a visible body of water; occasional presence of a body of water
	Biodiversity	Medium animal biodiversity (decrease in aquatic species), filamentous algae; high animal biodiversity (presence of aquatic species), aquatic vegetation; low animal and plant biodiversity
	Irrigation use	Yes; no
	Recreational activities	Possible; possible nearby; not possible

Two fractional factorial orthogonal designs were generated with SPSS® software. Two final sets of 18 profiles plus one (i.e. the "opt-out" alternative) each were selected.

Respondents were asked to choose between sets of four alternatives for twelve choice groups (six channel groups and six fountain groups). The hypothetical cost required for each alternative was presented in the form of an increase in the water bill, equal to 4, 12 and 20 € per month, depending on the alternative chosen (Tarfasa, Brouwer, 2013). The respondents were also offered the opportunity to choose none of the alternatives proposed against a zero increase in the bill.

For landscape of *fontanili*, images of a semi-dry canal and a full flow canal were presented, drawing from the websites of the Lombard consortia. For animal biodiversity, the information was derived with reference to the maintenance of a minimum vital outflow for the maintenance of aquatic species, which generally applies to natural water bodies (Puzzi *et al.*, 2005). For recreational aspects, the image of an accessible canal with a bike path was shown and a not accessible canal (Source Consorzio di Bonifica Chiese). For infiltration capacity, three scenarios were shown that present a high degree of infiltration, one medium and one low.

For *fontanili*, Bischetti *et al.* (2012) report data on the decrease in animal biodiversity following eutrophication and burial. In addition, the authors provide information on the vegetation present in partially buried springs, which is characterized by a massive development of filamentous algae. Therefore, the levels for biodiversity are: medium (decrease in aquatic species and the presence of filamentous algae); high biodiversity (presence of aquatic animal and plant species); low biodiversity.

For recreational aspects, the levels concern the impossibility of access, the possibility of enjoying the surrounding areas and the possibility of use for bathing. The images were taken from the Lombardy geoportal, which provides information on the *fontanili* census and from sites dedicated to tourism in the Province of Crema (area in which the most attractive *fontanili* are located). The attribute relating to the landscape has been defined on two levels that indicate the presence of a constant and visible body of water as opposed to the occasional presence of a body of water. Finally, the attribute that concerns the irrigation function is defined on the yes/no levels.

4. RESULTS

4.1. Socio-economic characteristics of the respondents

Table 2 summarizes some of the main characteristics of the 222 respondents, also through the comparison with census data of the population of Lombardy (Census ISTAT 2021). 36% of respondents are women, the average age is 37 years and most have a medium-high education (high school diploma and/or degree). The proportion employed is 57%, including employees, entrepreneurs and self-employed; the remaining 43% include, in part, students and pensioners. Finally, 9% of the sample, belong to environmental associations.

Tab. 2. Sample characteristics and comparison with the population.

Characteristic	Sample	Lombard population
Gender	women *36%*	Women *51%*
Age	37 years	45 years
Educational level	Medium-high *89%*	*52%*
Employed	*57%*	*68%*
Belong to Environmental association	*9%*	/

Source: survey and ISTAT census 2021.

4.2. Respondents' perception of irrigation and associated aquatic systems

Some information was requested about the general appreciation (and aversion) towards irrigation-related works. To support the choice, a set of options was presented using a 4-point Likert scale, in which indicating the degree of agreement with the claim submitted was asked. The options were numbered, assigning the lowest score to options indicating disagreement and the highest to those expressing a favourable opinion. A non-response was given a score zero. The results in Table 3 show that respondents have on average a positive perception of irrigated agricultural activity and related works; moreover, on average, they recognize the importance of irrigation for agricultural production and the economy of the territory.

4.3. Results of the choice experiment

Data was processed through the software NLogit ©, using two separate databases. The database of the fountains consists of 217 units. The random parameter logit (RPL) model was used for processing. The output of the models returns coefficients that, in the case of significance and positive sign, indicate that the level of the attribute associated is preferred regarding the level of the same attribute not included in the model.

The utility functions for the estimation of coefficients by means of the RPL model are as follows.

Tab. 3. Descriptive statistic of respondents' perception of irrigation and associated aquatic systems.

	Mean	Median	Mode	Standard deviation
The agricultural activity allows the territory to be enriched thanks to the watercourses necessary for irrigation)	3.37	4.00	4.00	0.83
Irrigation and related elements disfigure the landscape	1.78	2.00	2.00	0.88
Irrigation works are important for agricultural production and contribute to the territory	3.67	4.00	4.00	0.68

Utility function for irrigation canal:

$$U_C = OPTOUT + \beta_{BIOHIGH}BIOHIGH + \beta_{BIOMED}\mathrm{BIOMED} + \beta_{LANDSCAPEHIGH}LANDSCAPEHIGH + \beta_{RECRYES}RECRYES + \beta_{AQUIFHIGH}AQUIFHIGH + \beta_{AQUIFMED}AQUIFMED + \beta_{INCREASE}INCREASE$$

Where:
OPT-OUT = dummy for "None of the proposed irrigation canals"
BIOHIGH dummy for high biodiversity
BIOMED dummy for medium biodiversity
LANDSCAPEHIGH dummy for view of the full capacity canal
RECRYES dummy for the opportunity to carry out activities in the surrounding areas
AQUIFHIGH: dummy for high aquifer recharging capacity
AQUIFMED dummy for medium aquifer recharging capacity
INCREASE: monthly increase of water bill per household

Utility function for *fontanili:*

$$U_F = OPTOUT + \beta_{BIOHIGH}BIOHIGH + \beta_{BIOMED}BIOMED + \beta_{IRRIGYES}IRRIGYES + \beta_{RECRYES}RECRYES + \beta_{RECRNEAR}RECRENEAR + \beta_{WATER}WATER + \beta_{INCREASE}INCREASE$$

OPT-OUT = dummy for the option "None of the proposed irrigation canals"
BIOHIGH: dummy for high biodiversity
BIOMED dummy for medium biodiversity
IRRYES dummy for the possibility of use for irrigation
RECRYES dummy for the possibility of carrying out activities inside
RECRNEAR dummy for the possibility of carrying out activities in the surrounding areas
WATER dummy for the constant presence of a visible body of water
INCREASE monthly increase of water bill per household

4.4. Results for ecosystem services of irrigation canals

The estimates of the coefficients associated with the attributes of irrigation canals are represented in Table 4. The coefficient of the attribute for price is negative, which means that, as expected, the increase in the price decreases the utilities of the respondents. Furthermore, the "ASC" variable, which captures the effect of everything that was not considered in the model, is significant. All the coefficient of variables associated with the

Tab. 4. Output of RPL model for the estimation of coefficient of irrigation canals attributes.

	Coefficients	Standard error	z	Prob. |z|>Z*	95% Confidence Interval	
	Random parameters in utility functions					
BIOHIGH	1.99384***	.21462	9.29	.0000	1.57320	2.41448
LANDSCAPEHIGH	.49580***	.18322	2.71	.0068	.13670	.85490
RECRYES	1.57454***	.21946	7.17	.0000	1.14441	2.00467
	Non random parameters in utility functions					
ASC	.74394***	.20252	3.67	.0002	.34701	1.14088
ICREASE	-.11087***	.00846	-13.10	.0000	-.12746	-.9428
BIOMED	1.31918***	.13468	9.80	.0000	1.05522	1.58314
AQUIFHIGH	.27802***	.09077	3.06	.0022	.10012	.45593
	Distns. of RPs. Std.Devs or limits of triangular					
NsBIOHIGH	1.52536***	.15739	9.69	.0000	1.21688	1.83385
NsLANDSCAPEHIGH	1.27718***	.15431	8.28	.0000	.97474	1.57963
Ns RECRYES	2.12986***	.17824	11.95	.0000	1.78053	2.47920

***, **, * ==> Significance at 1%, 5%, 10% level.

highest levels of the attributes are positive and statistically significant. The output shows the presence of heterogeneity of preferences for the variables relating to high biodiversity, the possibility of carrying out recreational activities near the canals and the aesthetic aspect, whose coefficient is, in this case, positive and significant. The variable relating to the average recharging capacity is not significant, therefore not relevant in terms of the preferences of the respondents. McFadden's pseudo-R2 is equal to 0.23, considered an admissible value to establish the goodness of the model (Hensher *et al.*, 2005).

Through the estimated coefficient it is possible to estimate the WTP for attributes considered (Tab. 5). It corresponds to the ratio between coefficient of the price (INCREASE) and coefficient of the attribute.

Therefore, considering a scenario in which irrigation canals present high levels of each attribute considered, the WTP for the Lombard irrigation canals by the sample considered is approximately €40/ month per household.

Tab. 5. WTP for irrigation canals attributes.

Attribute	WTP (€/month)	WTP Confidence interval
High biodiversity	18	[15.7 24.1]
Medium biodiversity	12	[5.25 16]
Possibility to carry out activities	14.27	[11.4 20]
Aesthetic : full capacity canal	4.54	[1.4 8.5]
High aquifer recharge capacity	2.54	[1 4]

4.5. Results for ecosystem services of fontanili

Table 6 shows the results of the RPL model for the estimation of coefficient for attributes of *fontanili.*

Also in this case the coefficient linked to the increase of the price (*INCREASE*) is negative, confirming the hypothesis of consumer rationality; furthermore, the ASC variable has a significant coefficient. The output of the model indicates the presence of heterogeneity for high biodiversity, the irrigation function and the possibility of carrying out recreational activities in the *fontanili* and nearby. Instead, the coefficient associated with the visible presence of a body of water does not show heterogeneity and is not significant. McFadden's pseudo-R2 is equal to 0.17, which is a slightly out of the range value that ensures the goodness of the estimate, but is still considered acceptable (Doherty *et al.*, 2014).

WTP for attributes of fontanili, calculated through the ratio between the price coefficient and attributes coefficient, is shown in the Table 7.

Considering the scenario in which the attributes considered are provided at the highest level, the WTP for Lombard springs is approximately €30/month per household.

5. DISCUSSION OF THE RESULTS

The results show positive values for ES monetary value of the elements of the irrigation agro-ecosystem considered in the analysis.

With regard to irrigation canals, respondents show

Tab. 6. Output of RPL model for the estimation of coefficient for attributes of fontanili.

	Coefficients	Standard error	z	Prob. |z|>Z*	95% Confidence Interval	
	Random parameters					
BIOHIGH	1.14352***	.22552	5.07	.0000	.70150	1.58554
IRRIGYES	.68097***	.18629	3.66	.0003	.31584	1.04609
RECRYES	1.11199***	.13861	8.02	.0000	.84032	1.38365
RECRNEAR	.79619***	.19120	4.16	.0000	.42144	1.17094
	|Nonrandom parameters in utility functions					
ASC	.43004*	.26004	1.65	.0982	-.07962	.93971
INCREASE	-1.0089***	.00804	-12.55	.0000	-.11664	-.08513
BIOMED	.70763***	.12811	5.52	.0000	.45654	.95872
WATER	.19018	.19228	.99	.3226	-.18668	.56705
	Distns. of RPs. Std.Devs or limits of triangular					
NsBIOHIGH	1.40839***	.14894	9.46	.0000	1.11647	1.70031
NsIRRIGYES	1.39222***	.15155	9.19	.0000	1.09519	1.68925
NsRECRYES	.92894***	.13909	6.68	.0000	.65632	1.20156
NsRECRNEAR	.74374***	.17114	4.35	.0000	.40832	1.07917

***, **, * ==> Significance at 1%, 5%, 10% level.

Tab. 7. WTP for attributes of fontanili.

Attribute	WTP (€/month)	WTP confidence interval
High biodiversity	11,4	[7 15,8]
Medium biodiversity	7,1	[4,6 9,6]
Irrigation use	6,8	[3,2 10,5]
Recreational activities possible (bathing)	11,1	[8,4 13,8]
Recreational activities possible nearby	8	[4,2 11,7]

a positive WTP for the attributes related to biodiversity, aquifer recharge, landscape and recreational function. This justifies interventions of the irrigation and land reclamation consortia for the maintenance of irrigation canals aimed at preserving not only their capacity for water delivery, but also their ecological function, as well as the provision of recreational services.

The evidence also suggests particular attention should be paid to the conversion of traditional irrigation networks to pressure pipes or coated canals, since this would deprive the agro-ecosystem of elements of naturalness and ES that, as seen, have a value.

The biodiversity of the *fontanili* is particularly appreciated, showing a high WTP; similar results have been obtained for the possibility of using them for bathing.

An unexpected result regards the landscape attribute, represented by the continuous presence of a body of water in the *fontanile*. In this case, the coefficient is not significant, therefore this aspect is not taken into consideration by respondents in the choice between the alternatives proposed. This result, compared with the high WTP for activities, also nearby, is somewhat controversial, given the deep connections between aesthetic factors and choice of recreational places.

It is interesting to note that the respondents show a WTP for the possibility of productive use of *fontanili*, which is their original function that is instead disappearing nowadays. The appreciation of the community for the productive function suggests the importance of recovering and/or maintaining the original function of the *fontanili*, which support ecological processes dependent on the presence of water (nutrient purification, habitat for aquatic species, etc.). By adding the WTP for attributes it is possible to derive the consumer surplus generated through canals and *fontanili*. However, the value has been estimated only for some observable attributes through consumer preferences.

The interconnection between canals and *fontanili* (Gandolfi *et al*., 2006; Balderacchi *et al*., 2016) implies that the calculation of the monetary value of all ES included in the analysis can be attributed to irrigation canals. Indeed, in the case study analysed, ES of the *fontanili* can be considered as indirect ES of the irrigation canals. The interconnection between canals and *fontanili* also implies that variations in the aquifers recharge capacity of the canals, due, for example, to waterproofing, can lead to negative variations in the levels of ES of the *fontanili*, and, therefore, a lowering of their monetary value.

6. CONCLUSIONS

Water is increasingly becoming a scarce resource. Measures aimed at preserving water for future uses are an environmental and economic necessity. In terms of quantity, saving policies aimed at reducing withdrawals from surface and groundwater play a key role, in particular measures to improve irrigation efficiency, financed by huge resources deployed from public funds.

However, these measures do not take into account the return flow into the aquifer, which is available for "downstream" uses and other positive externalities. However, the excess water used for irrigation has not only a productive purpose, but also an environmental function. The case study analyzed in this paper is an example of this condition, since, in the study area, a fraction of water is useful for environmental purposes, including water to produce and/or maintain wetlands, riparian or terrestrial habitats.

The hypothesis of the capacity of an irrigated agro-ecosystem to produce ES, based on the literature review, has been reflected in the results obtained in this study regarding the WTP for uncoated irrigation canals and *fontanili*. Indeed, the results show a high WTP for the provision of services provided by these artificial aquatic systems. In particular, their biodiversity and recreational value are particularly appreciated. The WTP identified by canals and *fontanili* of the study area that have the highest levels of ES, respectively 40 and 30 €/month/household, reflects their approximate monetary value.

The aquatic systems considered are particular in relation to the theme of efficiency and ecological value, specifically, uncoated irrigation ditches are considered inefficient from the hydraulic point of view. They are often rich in vegetation, thanks to the presence of water, a factor that improves the aesthetic value of the landscape that, in turn, increases the attractiveness of the territory for tourist and recreational uses. As for surface water bodies, for which the maintenance of a minimum water flow is essential to provide the capacity of river ecosystems to offer ES, it is also essential to maintain an adequate water regime in the irrigation ditches for the development of vegetation and the related ES. Therefore, the volumes of water in the irrigation ditches play both a productive and environmental function, the latter in the form of positive externalities, quantified in monetary terms in this study.

This study also consider other ES of irrigation ditches supplied through the *fontanili*, following a cascade approach. This could be complemented by analyses involving the physical quantification of the ES considered, missing in this paper. The proposed case study refers to scenarios extrapolated from ecological and hydrological analysis on phenomena that occur in the study area that, however, do not allow physical mapping of the ES being studied according to the standards proposed by environmental accounting. This involves the need for ecological research of artificial aquatic environments such as those considered in the study presented. Therefore, it would be useful to map the artificial aquatic systems of an irrigated agro-ecosystem and investigate their ecological value. Indeed, not all irrigation ditches can provide ES, but only those rich in naturalness, which can improve biodiversity, landscape aesthetics and recreational attractiveness.

The implications of the monetary value of the environmental impacts of water use in agriculture concern the economic analysis to be implemented at the scale of the River Basin District. As seen, the main objective of the economic analysis is the identification of the environmental cost and the relative share of sectors of water use, to be internalized by some instruments. Therefore, the agricultural sector should contribute to the recovery of the environmental costs, through instruments such as compliance with requirements, taxes, irrigation fees and tariffs. However, the monetary value of the environmental benefits supplied by agricultural water use should be subtracted from the environmental cost of the agricultural sector. To ensure consistency in the assessment, the environmental cost should also be identified through a benefit-based approach, an option provided by the European Commission guidelines.

Since irrigated agriculture provides ES (with a positive monetary value), the measures aimed at the protection and enhancement of aquatic ecosystems linked to irrigation are relevant for the quantification of the environmental cost. Since these measures are financed through the consortium budget and/or other funds allocated to the agricultural sector, the cost incurred can be considered to be internalized, by the PPP principle.

Finally, the monetary values of the ES estimated in this study may provide useful guidance to include additional elements in a cost-benefit analysis with investments of projects for irrigation efficiency improvement. Generally, these analyses take into account investment costs, operation and maintenance costs, and benefits in terms of protection of upstream water bodies. The benefits of irrigation could be included taking into account the effective irrigation efficiency at basin scale (instead of classic irrigation efficiency). However, this would capture only the benefits of maintaining water for other uses. Nevertheless, as already mentioned, irrigation water performs other environmental functions which, without an appropriate monetary estimate, cannot be included in the analysis of the efficiency of water use. The results obtained are a useful tool to ensure the successful implementation of the WFD, which requires taking into account the different conditions within the territory, which need specific solutions (Sardaro *et al.*, 2018).

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Research article

Scientific information and cognitive bias in the case of New Breeding Techniques: exploring Millennials behaviour in Italy

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Abstract. The paper explores consumers' acceptance of New Breeding Techniques (NBTs) in the agri-food sector. Our main research question concerns the role of information in shaping consumers' attitude towards genetically modified food and new breeding techniques in agricultural production. To this extent, we use a Multinomial Logit Model to analyse changes or confirmations of prior opinions on food safety concerns and environmental risks associated with modern biotechnologies once scientific information has been provided. Our findings confirm the Bayesian hypothesis according to which people combine their prior belief with new information to converge scientific information in the case of food safety. We also found a higher probability of confirmation bias, with people less willing to change their prior beliefs, when environmental risks are concerned.

Keywords: genome editing, millennials, food safety, environmental risks, biotechnology, Multinomial Logistic Regression.
JEL codes: B4, Q5, Q00.

HIGHLIGHTS:

- Providing people with information on NBTs is important to allow people to make an unbiased judgment on them.
- Convergence towards new information received is lower when concerns are about environmental risks connected to NBTs and higher in the case of food safety concerns.
- Convergence to scientific information is lower for people with a higher level of knowledge on biotechnologies.
- Communication on new breeding techniques should carefully address people's concerns on potential environmental impacts to avoid consumer rejection of NMTs.

INTRODUCTION

New Breeding Techniques (NBTs) based on genome editing (GE) have progressed rapidly in recent years, succeeding in creating plants with novel traits. These techniques are summarized as New Plant Breeding Techniques (Lusser *et al.*, 2012).

Different from "first generation" GMOs, which include foreign genetic material from different organisms, NBTs, such as CRISPR/Cas or cisgenesis among others, involve the selective alteration of DNA at certain parts of the genome obtained by several methods such as point mutations, the excision or incorporation of new sequences. Possible applications of NBTs in agriculture include the development of new varieties resistant to abiotic or biotic stress i.e., climate change, drought, pests, or other diseases (Mishra, Zhao, 2018). In this respect, NBTs could facilitate sustainable agro-ecological intensification (Ryffel, 2017). Furthermore, NBTs are also developed to create new products as functional food or food with other desired attributes.

The debate on NBTs regulation has gained further attention since the Court of Justice of the European Union concluded, in 2018, that, according to the EU's regulatory framework for genetically modified organisms (GMOs), targeted, genome-editing mutagenic technologies are GMOs, regardless of whether any foreign DNA is present in the final variety (Purnhagen, Wesseler, 2020). Already, in 2013, the European Academies Science Advisory Council (EASAC) concluded that «the trait and product, not the technology, in agriculture should be regulated, and the regulatory framework should be evidence-based» (EASAC 2013). This statement was the result of a very comprehensive analysis – based on solid science published in the previous 20 years – on the risks and benefits of crop NBTs, which did not find evidence for an intrinsically higher risk of genetic engineering in comparison to conventional breeding technologies such as mutagenesis. Since then, many scientists and other stakeholders have been calling for liberalisation of NBTs claiming that it is not possible to distinguish new varieties from those obtained by other more consolidated genetic methods such as mutagenesis or from mutations that happened in nature (Broll *et al.*, 2019; Callaway, 2018; Dederer *et al.*, 2019; Zimny, Sowa, 2021). According to Halford (2019) and many other scholars, there is an urgent need for the European Union to shift its position on plant biotechnology if agriculture is to meet the challenges of coming decades.

In 2021, the European Commission published a new study, on request by the Council of the EU, concluding that while NBTs could contribute to more sustainable food systems, current EU GMO regulations pose challenges to the development of innovative genetic technologies. According to this report, views from MS and stakeholders were diversified. In Europe, for example, biotechnologies are sometimes considered as potentially harmful to both humans and nature (Marangon *et al.*, 2022; Lucht, 2015; Malyska *et al.*, 2106), even if the general opinion is characterized by limited, and often negatively biased knowledge. Individuals' risk perception is the subjective judgement that might diverge from the technical risk estimate provided by experts (Slovic, 1987; Van Kleef *et al.*, 2007) on the basis of psychological, attitudinal, and cultural factors (Verbeke *et al.*, 2007). Moreover, some advocacy groups such as Greenpeace[1], emphasizing several concerns such as side effects and off-target effects, as well as the possibility of negative socio-economic impacts, make a claim for a restrictive regulatory approach or underline questions of corporate power surrounding plant genome editing (Helliwell *et al.*, 2019).

With this study we aim to contribute to the literature providing additional evidence regarding a) the opinion of Italian university students on NBTs; b) understanding to what extent, if present, consumers' attitude towards NBTs concerns mainly food safety or environmental risks; c) the role of new information in modifying people's attitude towards genetically modified food.

1. THEORETICAL FRAMEWORK, OBJECTIVES OF THE STUDY AND RESEARCH QUESTIONS

In the light of this debate, researchers have paid increased attention to consumers' attitudes towards GM food and the NBTs and to the role of information. According to several studies, consumer knowledge of genetic techniques is generally low (McFadden, Lusk, 2016; Colson, Rosou, 2013; Hwang, Nam, 2021). A study by McGarry *et al.* (2012) compares the knowledge of consumers in the United States, Japan, and Italy, showing that US consumers are more likely to be at least somewhat familiar with GMOs (40.9% reported being somewhat or very familiar) compared with Italian (28.0%) and Japanese consumers (33.3%). Others have highlighted consumer aversion expressed in preferences for production bans or mandatory labels (Carlsson *et al.*, 2007; Costanigro, Lusk, 2014). Several approaches have been utilized such as estimating the willingness-to-pay to avoid GM food (Frewer *et al.*, 2013; Hess *et al.*, 2016), theoretical models related to perceived risks and benefits (Bredahl, 2001; Frewer *et al.*, 2016), responses to information (Huffman *et al.*, 2007; Lusk *et al.*, 2004), and psychological factors (Lusk *et al.*, 2014).

Beghin and Gustafson (2022) conducted an extensive survey of existing studies on consumers' attitude

[1] https://www.greenpeace.org/eu-unit/issues/nature-food/45559/new-gmos-danger-ahead/

about NBTs-based food, showing that limited familiarity together with concerns about their naturalness can explain why consumers prefer more traditional products. Their study also explains that acceptance is higher when consumers perceive tangible benefits, such as nutritional value or more sustainable production processes.

In analysing the aversion to biotechnology, Lusk *et al.* (2018), explored the main causes of heterogeneity in consumer preferences for GE food and food policies by determining consumers' acceptance of GE foods or plant breeding technologies. Their results highlight the presence of small differences in consumer preferences for policies related to different plant breeding methods. However, consumers support the idea that GE food products should be regulated based on risk analysis of their impact on health and the environment rather than the process used to create new varieties. Support or opposition for GE food depends as well on public trust in technology developers (Lucht, 2015; Siegrist *et al.*, 2012). Other authors pointed out that one of the relevant obstacles in the public acceptance of GM and GE is related to information received by consumers from the media, internet, and other sources (Ishii, Araki, 2016; Lucht, 2015; Wunderlich, Gatto, 2015).

Consumer acceptance is also affected by several factors which include ethical and cultural values as well as health concerns (Lusk, Coble, 2005; Costa-Font *et al.*, 2008). As specified in the empirical literature, consumer knowledge on this topic is limited due to a lack of consumer education. Marette *et al.* (2020), in analysing the willingness to pay for GE/GMO apples in Europe and the US, showed a tangible concern for GE/GMO varieties in both areas, with French consumers raising more concerns in comparison to the US, and preferring more information. Other studies reported that limited knowledge and biased information make consumers incapable of correctly evaluating what concrete risks associated with these products (Siegrist, 2008; McFadden, Lusk, 2016). Fernbach *et al.* (2019), demonstrated that inadequate knowledge on science and genetics generates a major opposition to GM foods, while lesser negative judgments are correlated with a higher knowledge level on GM products. However, some of the literature suggests that consumers are more likely to accept GM food if they recognize some tangible benefit such as reduction in the use of pesticides (Lusk *et al.*, 2015; Gaskell *et al.*, 2003) or other environmental benefits (Delwaide *et al.*, 2015; Lusk *et al.*, 2004; Gaskell *et al.*, 2003). In addition, scholars also find that if new technologies improve nutritional content, then they become more acceptable (Lusk *et al.*, 2015; Lusk *et al.*, 2004; Grunert *et al.*, 2001; Pham, Mandel, 2019). People also positively evaluate the fact that NBTs could contribute to food security in developing economies (Lusk *et al.*, 2004; Hossain *et al.*, 2003).

Hence, adequate information allows consumers to change or re-address their opinions. In this perspective, the interesting works by Siegrist (2008), Lusk *et al.* (2015), Pakseresht *et al.* (2017) and Edenbrandt *et al.* (2018), emphasize that consumers may increase their preferences and willingness to pay for GM food alternatives when information is provided about health, nutrition, and environmental benefits. De Marchi *et al.* (2020), explore the role of information in affecting consumers' preferences for food products in the case of cisgenic versus conventional apples, demonstrating that information on health-related benefits, particularly environmental benefits, contributes to generating a positive and favourable opinion on cisgenic food. Recently Ferrari *et al.* (2020), investigated students' attitudes towards GE food in the Netherlands and Belgium and found that they were determined by environmental concern (negative) and objective knowledge (positive). Key factors influencing preferences for GE labelling were a non-hard-scientific background, knowledge about relevant policies and a negative attitude towards GE food (Ferrari *et al.*, 2020). A recent review of selected articles published in the last 16 years (2005-2021) assesses that public knowledge of GM technology and products remains the main factor concerning general attitude and acceptance, followed by socioeconomic factors, trust in public authorities and regulations, media, and communication (Hermosaningtyas, 2021).

Recently, Marangon *et al.* (2022) conducted a choice experiment to investigate Italian consumers' preferences for bread made with gene-edited wheat. Results demonstrate that consumers do not know very much about breeding techniques, therefore it is suggested to develop better communication strategies for society to comprehensively understand biotechnologies and support policymakers in the definition of informed regulations.

This brief literature review shows that there is still some reluctance with respect to GM and GE as consumers don't fully trust them and are not fully aware of their potential benefits. Nevertheless, consumers' behaviour is not homogenous worldwide, with European consumers showing a higher level of skepticism. Consumer non-acceptance of enabling agri-food technologies and their products, including genetic modification, is an important barrier to their commercialization (Frewer, 2017).

Our study has a twofold objective: first, we explore consumers' attitudes towards genetically modified food; second, we determine how potential consumers assimilate scientific information on NBTs in making an ex-post opinion after receiving information. Our analysis focuses on a specific segment of consumers made by university students. The so-called Millennials are being investigated by several scholars (Bollani *et al.*, 2019; Oz *et al.*, 2018; Cavaliere, Ventura, 2018; Coderoni, Perito, 2021; Ferrari *et al.*, 2021) to explore the possible generational shift in attitudes and purchasing decisions. Millennials are considered more informed than others with respect to the environment and also more concerned about the environment and the ethical attributes of products (Cavaliere, Ventura, 2018).

Individuals' decisions whether to support or oppose GM crops are made under uncertainty. According to the Bayesian decision theory, when deciding under uncertainty, individuals combine a prior belief with new information to form an ex-post belief. Under the Bayesian theory, individuals process information optimally and converge to the new information received. In doing so, individuals allocate weights to prior beliefs and new information. The first hypothesis this work wants to test is whether exposure to scientific information changes the perception of consumers' information on GM. People elaborate new information received and converge to it (McFadden, Lusk, 2015; De Marchi *et al.*, 2022; Son, Lim, 2021).

In reality, ex-post beliefs do not always converge to information for several reasons. If people's behaviour does not converge towards the scientific information received, it means that higher weight is attributed to the prior belief, e.g., there is some form of prejudice. In the case of GM foods, there is apparently a disconnection between scientists' opinions and public opinion. These forms of violation of the Bayesian decision theory are defined as cognitive bias. According to Jang (2014) individuals with higher levels of perceived knowledge about GM are more likely to converge to information.

The second hypothesis of this study refers to the confirmation of prior beliefs. Current beliefs prevail in formulating opinions that diverge from the new information received (Grunert *et al.*, 2003; McFadden, Lusk, 2015; Fernbach *et al.,* 2019; Pham, Mandel, 2019). The reason could be that many people do not receive or accept scientific information, or it could be that they place greater weight on other types of non-scientific information (McFadden, Lusk, 2015). In making their opinion, consumers may take into consideration several concerns such as the unexpected damages of GM crops/food to the environment, destruction of biological diversity, food safety concerns, religious and moral problems. Wuepper *et al.* (2018), with respect to German consumers, found that attitudes seem to mostly reflect fundamental preferences. Some authors think that scientific research data are often intentionally marginalized when reporting science, while media attention on specific issues can be unbalanced and selective (Curtis *et al.*, 2008; Malyska *et al.*, 2016; McCluskey, Swinnen, 2011). Despite all the scientific findings, consumers still have disbelief about accepting the new information received and tend to confirm their prior beliefs.

The third hypothesis states that people having a higher knowledge tend to confirm their prior beliefs. Consumer knowledge can be distinguished between perceived and actual knowledge, that is between what consumers think they know and what they really know. As a consequence, there might be an underestimation of the knowledge level that may affect consumers' attitudes and behaviours (Fernbach *et al.*, 2019; Jang, 2014; McFadden, Lusk, 2015; McFadden, Lusk, 2016; Huffman *et al.*, 2007; Hwang, Nam, 2021).

The following section describes methodology details. The model description is in section 3. The discussion of the results is presented in section 4, while section 5 concludes.

2. RESEARCH METHODOLOGY AND DATA

a. Questionnaire and data gathering

To address our research questions, we developed two different tools: a questionnaire and a five-minute video in collaboration with scientists, designed to familiarize respondents with different breeding technologies used for different crops and objectives. Both instruments were tested in a pilot study and then submitted through an online survey.

Links to the online tools were sent to professors teaching in 15 universities selected to have a balanced distribution in terms of geographical area and academic subjects, thus including humanities, social sciences, and scientific disciplines). The professors submitted the tools to both their first degree and the master's degree classes, during the academic year 2019/2020.

The number of individuals who responded to the questionnaire was 506. Sixty-one percent of the survey sample was comprised of females, 25% held a Bachelor's degree and were enrolled in a Master's degree.

Descriptive statistics of the sample are illustrated in Table 1.

The questionnaire was divided into 6 sections as described in Figure 1. The first section regarded demographic questions. In the second section – the self-assessment of knowledge – respondents were asked if and how much they know about genetic techniques. In the third section, ten questions were submitted to verify

Tab. 1. Descriptive statistics of respondents.

Gender	Freq.	Percent
Male	197	*38.93*
Female	309	*61.07*
Total	506	*100*
Faculty	Freq.	Percent
Humanities and Social Science	28	*5.5*
Economics	108	*21.3*
Engineering and Medical Studies	52	*10.28*
Agricultural Science, Biological Science and Biotechnology	318	*62.8*
Total	506	*100*
University Degree	Freq.	Percent
First Degree	380	*75.1*
Master	126	*24.9*
Total	506	*100*

the real level of knowledge. The fourth section contained direct questions to verify the willingness to purchase GM products and concerns about perceived risks in the two areas previously described i.e., food safety and environmental risks. Both categories of risk represent societal concerns i.e., potential damage for the population. Societal concern refers to hazards with the capability of generating socio-political responses (Ball, Boehmer-Christiansen, 2007). Drivers can be intrinsic as a genuine predictable risk but also based on ethical considerations, lack of trust or particular groups activities (Morgan, Henrion, 1990). In the fifth section, we asked some questions related to the desired governance level for NBTs e.g., at what level should authorization or labelling be regulated. Between the fifth and sixth section, students had to watch a 5-minute video where scientific information was provided by biotechnologists participating in the same research project. After watching the video students were again asked the questions already posed in the third section in order to check the changes in their willingness to purchase and in perceived risks after having received some "easy to digest" information based on scientific evidence. A brief overview of the questions asked is described below[2].

b. Variables construction

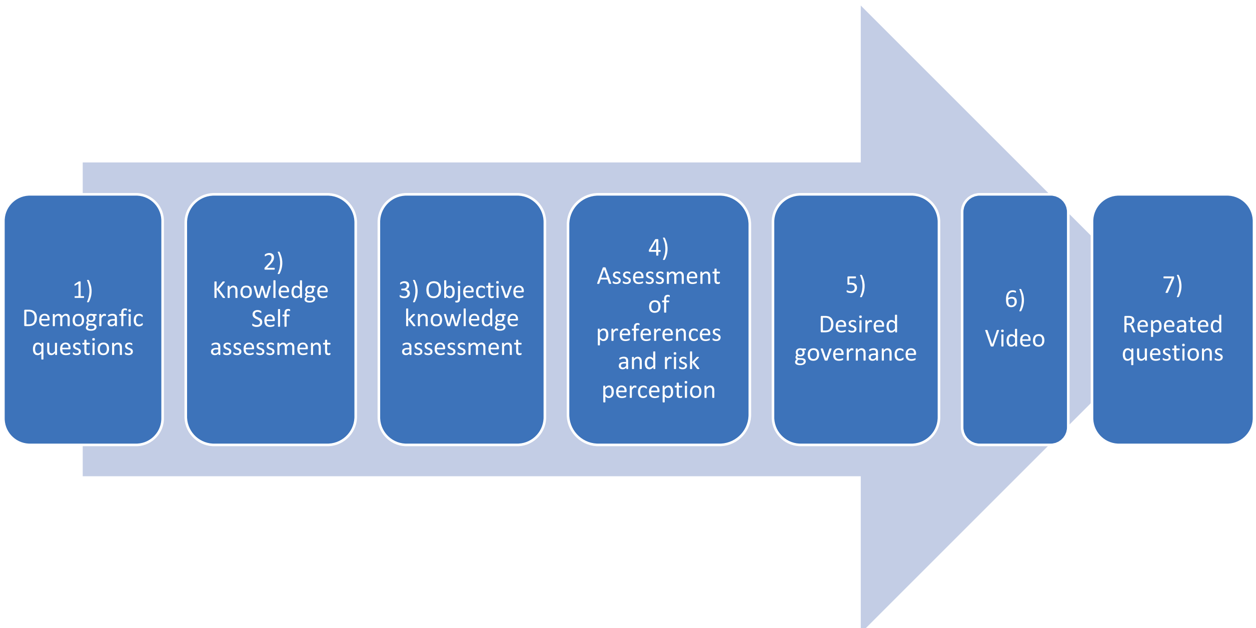
Based on the responses to the questionnaire, we built several variables.

From the demographics we obtained two variables: *Gender* and the *Study Field* (1= Humanities and Social Sciences; 2: Economics; 3: Engineering and Medical Schools; 4: Agricultural Science and Biotechnology).

The *Perceived Knowledge* variable is the result of the self-assessment of knowledge on GM food (2[nd] section). Similarly, to McFadden and Lusk (2014) questions to determine subjective knowledge about GM food ranged

[2] Questionnaire available in the complementary material.

Fig. 1. Details of the online survey.



on a five-point scale from "Very Unknowledgeable" to "Very Knowledgeable".

In the third section, a group of ten questions were posed to determine how much the students really knew about GM crops. Questions regarded specific breeding techniques, the proportion of maize and wheat areas planted with GM seed or which GM crops were available on the market, if they could be sold in Italy and other questions with Yes/No answers. Then, according to the score from the ten answers we created a new variable denominated *Actual Knowledge*, split into four levels according to increasing levels of knowledge about GM crops/foods and regulatory issues. Additionally, we computed the gap between actual and perceived knowledge for each individual and created a variable named *Change_k*.

In the fourth section we asked if "Food that has genetically modified ingredients is safe to eat" and if "Growing genetically modified ingredients is safe for the environment". The risks regarding food safety or the environment represent two forms of possible negative outcomes associated with GM crops/foods.

We used a set of four answers (from "strongly disagree" to "strongly agree") to measure opinions about the two potential risks and included an "I do not know" option. In both cases, we asked a question that measured confidence in the response to the previous agreement question.

The responses obtained from the fourth section of the questionnaire related to the willingness to purchase GM products and concerns about perceived risks in the two areas previously described i.e. food safety and environmental risks were elaborated to create a *prior belief variable*.

Participants were classified in three groups for each risk category (food safety or environment):

- *Believers*: Participants who believe GM foods are safe to eat or do not cause environmental damage (answers *I agree,* and *I strongly agree*);
- *Denier*s: Participants who deny GM foods are safe to eat or can cause environmental damage (answers *I do not agree* and *I somewhat do not agree*);
- *Neutral*s: Participants who neither believe nor deny GM foods are safe to eat or can cause environmental damage (answer *I don't know*).

In the fifth section we asked about the preference for mandatory labelling and which authority should take such decisions. Accordingly, to the answers to the two questions on the preferred level of governance (EU, State, Region) we created a dummy variable (*EU-centric*).

In the last section, the questions in section 3 were repeated.

Based on the observed changes people were classified in the following three groups:

a. *Conservative:* when the individual kept their initial opinion according to the new information;
b. *Convergent*: when the individual changed their initial opinion according to the new information;
c. *Divergen*t: when the individual changed their initial opinion contrary to the new information.

Statistical details are in Table 2.

Table 2 shows the descriptions and means of explanatory variables used in econometric analysis. The model was estimated using 506 observations, the number of respondents to the survey.

The Chi-square test of independence[3] was used to test the association of "knowledge" variables with those regarding the study field and gender (Tab. 3). For two of the four variables' pairs tested we obtained a dependent relationship. There was a significant association between perceived knowledge and study field on the one hand, and actual knowledge and study field on the other.

3. EMPIRICAL MODEL

In the study, we want to understand the effects of subjective prior beliefs on the acceptance of scientific information. As anticipated in the introduction, people may trust the information that they have received (Bayesian hypothesis) or they can distrust it assigning more weight to their prior belief. According to Jang (2014), which examined whether participants chose to read scientific information that confirmed or contradicted a prior belief, a high level of perceived knowledge can cause people to confirm a prior belief.

Given that the dependent variable is not specified in any order of importance or magnitude, this study used an unordered Multinomial Logit Model (MNL) in modelling the information-processing outcome categories. We estimate two MNLs, one for each category of societal risk for which prior and ex-post beliefs were investigated with the survey.

The dependent variable for the model is a discrete variable taking a value ranging between 0 and 2 (*Conservative* information = 0; *Convergent* = 1, *Divergent* = 2).

We tested for the following hypothesis:

H0: Bayesian hypothesis (people converge to the information received) i.e. individuals process information optimally and converge to the new information received;
H1: Some people violate the Bayesian decision theory confirming a prior belief that diverges from the new information received (confirmation bias);

[3] Test of Independence only assesses associations between categorical variables and cannot provide any inferences about causation.

Tab. 2. Descriptions and means of variables used in logit model estimations.

Variables names	Description	Value	Food safety Mean	Environment Mean
Info_process	**Dependent variable**: Conservative, Convergent, or Divergent	Variable ranging from 0 to 2		
Believers	Respondents who believe GM products do not present additional risks for food safety or the environment	Variable coded 0/1	0.523	0.227
Neutrals	Respondents who don't have an opinion on GM products presenting additional risks for food safety or the environment	Variable coded 0/1	0.233	0.138
Deniers	Respondents who believe GM products do present additional risks for food safety or the environment	Variable coded 0/1	0.243	0.634
Perceived_K	Level of presumed knowledge in the field of genetic breeding techniques	Score ranging 1 (no knowledge) to 4 (optimal knowledge)	2.474	2.474
Actual_K	Level of objective knowledge on scientific information on GM crop/food.	Variable ranging from 1 (no knowledge) to 6 (optimal knowledge)	3.333	3.333
Change_K	Difference between actual knowledge on scientific information on GM crop/food and perceived knowledge	Variable ranging from 1 to 5	2.867	2.867
EU-centric	Dummy accounting for the effects of regulating biotechnology	Variable coded 0/1	1.612	1.612
Gender	Dummy variable equal to 1 for female and 0 for male.	Variable coded 0/1	0.610	0.6103.302
Faculty	Study field	Variable ranging from 1 to 4 Coded =1 for Humanities and Social Sciences 2= Economics; 3= Engineering and Medical Schools. 4= Agricultural Science and Biotechnology,	3.302	3.302

Table 3. Chi-square values and significant levels of variables pairs.

Variables	Chi-square	Degree of freedom	Significance level
Perceived knowledge/study_field	42.764	12	0.000*
Actual knowledge/study_field	29.087	8	0.000*
Perceived knowledge/gender	6.817	3	0.103
Actual knowledge/gender	2.431	2	0.297

Note: Significance at 0.05.

H2: People who have a higher knowledge tend to confirm their prior belief (they are more skeptical towards new information).

The Logit model for multiple choice problems takes the following form:

$$Pr\{Y_i = j\} = \frac{\exp(x_i\beta_j)}{1+exp\{x_i\beta_2\}+exp\{x_i\beta_3\}+\cdots+exp\{x_i\beta_M\}}; j = 1,2 \ldots M \quad (1)$$

Where x_i is a K-dimensional vector containing the characteristic s of individual i (including an intercept term) and β_j denotes a vector of alternative-specific coefficients. We estimate K-1 slope coefficients plus an intercept term for all but one of the alternatives.

Caution must be used in interpreting the Multinomial Logit coefficients, as their significance depends on the chosen baseline outcome category that determines which specific log odds ratio is estimated. Therefore, the coefficients and estimated standard errors will change according to the chosen baseline category because they are related to the number of observations in the two appropriate categories. If a baseline category includes few observations, then the standard errors could be higher for all associated coefficients. However, the choice of the baseline does not affect the predicted probability and their standard errors. This problem can be overcome through the use of marginal effects (Scott-Long, 1997; Paolino, 2021).

The marginal effects in this model are the effect of changing a regressor by one unit on the probabilities of choosing each alternative:

$$\frac{\partial \Pr(Y_i=j)}{\partial x_i} = \Pr(Y_i = j|x)\left(\hat{\beta}_{jk} - \sum_{j=1}^{M}\hat{\beta}_{jk} * \Pr(Y_i = j|x)\right) \quad (2)$$

The term $\left(\hat{\beta}_{jk} - \sum_{j=1}^{M} \hat{\beta}_{jk} * \Pr(Y_i = j|x)\right)$ signs the marginal effects, it is possible to observe that the sign of the marginal effects may or may not correspond to the sign of the coefficient estimated itself.

4. RESULTS AND ROBUSTNESS TESTS

Approximately 52.37% of the sample considered that GM food is safe to eat prior to receiving information, approximately 23.32% were unsure, and the remaining 24.31% did not consider GM foods as safe. Regarding environmental risk, approximately 22.73% of the sample considered GM production safe, approximately 13.83% were not sure, and the remaining 63.44% did not consider it risk-free. Therefore, participants' perception of risk was higher in the case of potential environmental damage with respect to food safety.

Relative frequencies of prior beliefs and ex-post beliefs for both societal risks are reported in Table 4 and 5.

The first objective of our analysis was to determine if information processing was dependent on prior beliefs. As described previously, students were given the same questions after receiving the new information in order to check if they had changed their prior beliefs and formed new ex-post beliefs.

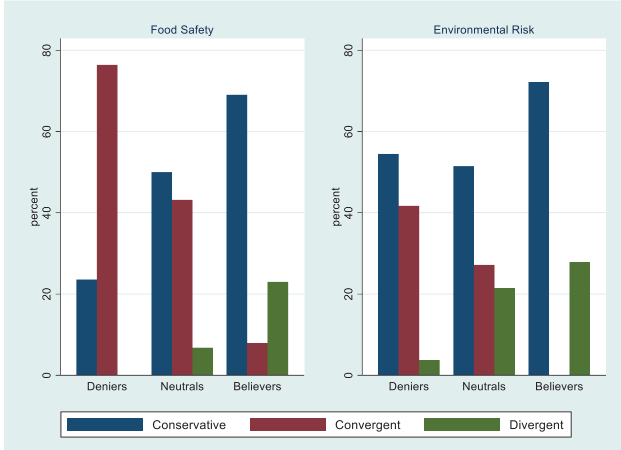
Tab. 4. Descriptions and relative frequencies of prior beliefs.

Food safety	Freq.	Percent
Believers	265	*52.37*
Neutrals	118	*23.32*
Deniers	125	*24.31*
Total	506	*100.00*
Environment		
Believers	115	*22.73*
Neutrals	70	*13.83*
Deniers	321	*63.44*
Total	506	*100.00*

Tab. 5. Descriptions and relative frequencies of information processing categories.

Food safety risk	Freq.	Percent	Cum.
Convergent	200	*39.52*	*39.53*
Conservative	212	*41.90*	*81.42*
Divergent	94	*18.58*	*100*
Total	506	*100*	
Environmental risk	Freq.	Percent	Cum.
Convergent	102	*20.16*	*20.16*
Conservative	258	*50.99*	*71.15*
Divergent	146	*28.85*	*100.00*
Total	506	*100*	

Fig. 2. Assimilation of scientific information on Food Safety and Environmental Risks.



Ex-post beliefs with respect to both types of risks were tested to be dependent on *prior beliefs* (Person's Chi squared test <0.05). Figures 2 illustrates how interviewed students with different prior beliefs assimilate scientific information on GM foods with respect to their beliefs on food safety and environmental risk.

When considering the food safety issue, a student in the *Believers* category is more likely to be in the conservative group, not changing his/her opinion. A small group of students converged after receiving information, while others diverged. The majority of people who were categorized as deniers, on the other hand, converged to information. This implies that the new information prevailed over prior beliefs. Finally, students in the Neutral category are more likely to be either in the convergent or conservative categories, and least likely to be in the divergent one. This indicates that students who previously were unconcerned about food safety either hold their prior belief or align with information while only a few did not align with the information received.

We obtain a different pattern of results where the risk for the environment is concerned. Again, participants in the *Believers* grouping are more likely to be conservative, not changing their prior belief. Students who previously believed that GM production was unsafe for the environment e.g., students in the *Deniers* outcome, are instead split between the convergent and conservative groups with a majority in the last category where the prior belief prevails. Finally, students in the

Tab. 6. Marginal effects in the food safety model.

	conservative		convergent		divergent	
	dy/dx	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.
Believers	0.217	0.056***	-0.357	0.053***	0.140	0.025***
Deniers	-0.127	0.065**	0.280	0.063***	-0.156	0.018***
Perceived_k	0.086	0.035**	0.009	0.029	-0.096	0.024***
Change_k	0.033	0.027	0.021	0.022	-0.055	0.019**
Education	0.090	0.046**	-0.058	0.037	-0.031	0.031
Gender	-0.021	0.043	0.043	0.035	-0.022	0.030
EU_centric	-0.024	0.041	-0.023	0.034	0.047	0.029

Estimates are from Multinomial logit using 506 observations. Standard Errors in parenthesis. * Indicates statistically significant at 10% level. ** Statistically significant at 5% level. *** Statistically significant at 1% level.

Neutral category, move towards the conservative and convergent group.

Our second objective was to test the three hypotheses about information processing. To this extent we assumed the information-processing outcome categories (conservative, convergent and divergent) as dependent variables. Table 6 presents marginal effects with regard to consumers' beliefs towards the food safety issue, while Table 7 reports the marginal effects as concerns consumers beliefs about the environmental risks linked to GM crops[4]. Robustness checks are discussed below.

When considering the risk associated with food safety, interviewed students who had been classified as *believers* behave in a conservative way while those classified as *deniers on the basis of their prior belief* show a higher probability of being convergent. Therefore, in both cases, the Bayesian Hypothesis (H0) holds, i.e., people converge to the new information. Our findings in comparison to McFadden and Lusk (2015) show that people classified as deniers were less likely to be divergent. In the same case people keep their original belief (deniers conservative or divergent significant). This result suggests that the H1 holds. The variable *Change_k* is significant and negative in the divergent group and conversely, positive, and significant in the conservative outcome. These results show that, in the case of food safety, people who realize that their knowledge is limited are more willing to change their previous ideas and converge to scientific information[5], confirming the Bayesian hypothesis H0.

The variable *perceived_k* is positive and significant in the conservative outcome and negative in the convergent and divergent one, whereas participants with a higher level of perceived knowledge are more likely to suffer from cognitive bias. This result is similar to Jang (2014) who showed that people having a high level of perceived science knowledge are more likely to read scientific information and confirm a prior belief. In the same vein, we also found that students enrolled in scientific degrees are more likely to be in the conservative group trusting their own knowledge, i.e., H2 holds.

The variable related to the preferred level of governance (*EU-centric)* is not significant for all the outcomes. Finally, no gender effect has been detected.

The second model regards students' beliefs about environmental risks linked to cultivation of genetically modified crops. In this case, relative to participants in the neutral group, believers were more likely to be conservative while deniers were more likely to be divergent. This means that they all gave a higher weight to their prior beliefs. H0 is rejected for participants classified as deniers and in this case H1 holds.

Both knowledge variables, the one regarding self-assessment and the change between perceived and actual knowledge, are positive and significant in the conservative model; the finding suggests that people who (wrongly) consider knowing more about biotechnologies are more likely to suffer from information bias and do not converge to new information they receive from a scientific source, i.e., H2 is confirmed. Again, students enrolled in science degrees show a negative and statistically significant marginal effect in the convergent group. In this case the prior belief is not changed by the new information received, confirming H2.

[4] It is important to keep in mind that the marginal effects of a Multinomial Logit refer to changes in the probability of one outcome, while raw coefficients to the ratio of log probability of one outcome and the probability of baseline outcome. A variable can affect one probability and the baseline probability and positively impact on the ratio, but negatively affect the one probability (https://stats.stackexchange.com/users/23853/maarten-buis).

[5] We run a MNL by considering the variable actual knowledge (*actual_k*) in place of *change_k*. Our findings are similar to those of McFadden and Lusk (2015), which indicated that people with a high level of scientific knowledge tend to be conservative.

Tab. 7. Marginal effects in the environmental risk.

	conservative		convergent		divergent	
	dy/dx	Std. Err.	dy/dx	Std. Err.	dy/dx	Std. Err.
Believers	0.313	0.044***	-0.353	0.024***	-0.040	0.399
Deniers	-0.053	0.055	0.130	0.044 **	-0.184	0.044***
Perceived_k	0.073	0.037*	-0.037	0.032	-0.036	0.018
Change_k	0.053	0.028*	-0.022	0.023	-0.031	0.026*
Education	0.008	0.045	-0.071	0.040 *	0.030	0.029
Gender	-0.040	0.047	-0.037	0.038	-0.046	0.028
EU centric	-0.057	0.043	-0.107	0.037**	0.049	0.027*

Estimates are from Multinomial logit using 506 observations. Standard Errors in parenthesis. * indicates statistically significant at 10% level. ** statistically significant at 5% level. *** statistically significant at 1% level.

The gender variable is not significant.

Figures 3 and 4 show the median and distribution of students' predicted probabilities of information process for each category, across deniers (Fig. 3) and believers (Fig. 4). Note that there are large differences between believers on the probabilities for conservative and convergent, and smaller ones for divergent.

To test the robustness of our estimates, several models were run introducing new independent variables. Firstly, we used *actual_k* in place of *change_k*; secondly, we considered an interaction term between *perceived_k* and *believers* on the one hand; and *perceived_k* and *deniers* on the other. Results from the robustness check confirm our findings[6].

Furthermore, we verified whether the models fit the data by looking to the Global likelihood ratio test. This equals -369.360 in the food safety model and -393.701 in the environmental risk model, indicating that in both models we can reject the null hypothesis with a high degree of confidence. We also conducted a LR and Wald test to investigate whether specific variables have effects, either singly or jointly, for each independent variable. Both tests led to very similar conclusions. In the food safety model, we found that believers, deniers, perceived knowledge, changes in knowledge and faculty effects are significant; therefore, rejecting the hypothesis that these variables do not affect the value considered important for the information process[7] (Tab. 8). We conducted a Wald test for each independent variable and the result was similar to LR test. We also tested for the property of independence of irrelevant alternatives (IIA). This stringent assumption of the Multinomial Logit requires

Fig. 3. In-Sample Predicted Probabilities, by deniers (Boxplots).

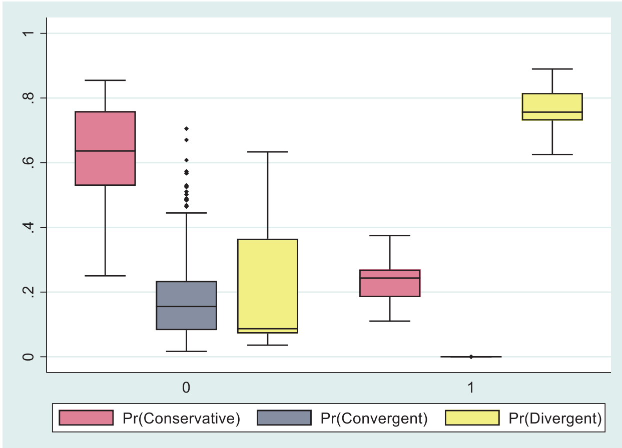
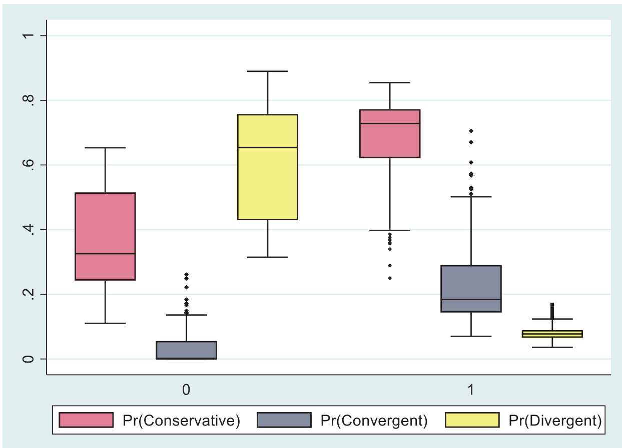


Fig. 4. In-Sample Predicted Probabilities, by believers (Boxplots).



[6] Results are not reported in the study, but they are available upon request.

[7] The variable's effects on believers, deniers, perceived knowledge, changes in knowledge are significant at 5%, while faculty at 10%.

Tab. 8. LR tests for independent variables (N=506) in the food safety model.

	chi2	df	P>chi2
Deniers	34.238	2	0.000 (*)
Believers	64.479	2	0.000 (*)
Perceived_k	13.028	2	0.001 (*)
Change_k	8.228	2	0.016 (*)
Study_field	5.233	2	0.073 (*)
Gender	1.742	2	0.419
EU centric	2.793	2	0.247
Info	0.121	2	0.941 (*)

Tab. 9. LR tests for independent variables (N=506) in the environmental risk model.

	chi2	df	P>chi2
Deniers	23.262	2	0.000 (*)
Believers	0.009	2	0.996
Perceived_k	3.483	2	0.175
Change_k	3.786	2	0.151
Study_field	0.914	2	0.633
Gender	2.430	2	0.297
EU centric	8.755	2	0.013 (*)
Info	0.310	2	0.856

that the inclusion or exclusion of categories does not affect the relative risks associated with the regressors in the remaining categories (Long and Freese, 2014). The results of the test confirm that IIA has not been violated.

In the environmental risk model, we detected significant effects for believers and deniers at 1%. The Wald test confirmed the significant effect of deniers and EU regulation. The results of the test also in the environmental risk model confirm that IIA has not been violated (Tab. 9).

We validated the classification model by using a confusion matrix, accuracy test and error rate (ER). The overall accuracy demonstrates a performance equal to 84% with an error value equal to 15.6% for the consumption model and 57.9% with an ER of 42%. Results of the ACC, which is the probability of performing a correct classification, show a high probability for the consumption model. Details are provided in the Appendix.

5. DISCUSSION AND CONCLUSIONS

Although scientists consider NBTs as a set of technologies that can overcome some of the criticism associated to transgenics techniques, at the same time addressing many challenges linked to sustainable intensification in agriculture, most people do not distinguish between the two approaches and still maintain relevant prejudice on the commercial use of NBTs. These cognitions may change over time as reported by Van Giesen, Fischer and van Trijp (2018). Whereas at the beginning of the technological innovation process, people rely relatively more on affect or emotional responses, later on reliance on cognition increases.

In this paper, we have investigated Italian university students' concerns with regard to food products obtained using New Breeding Techniques. We surveyed a sample of 506 Italian students online belonging to 15 universities, asking them questions on food safety and environmental risk. The majority of these students declared to be unaware or have a very limited knowledge of GM techniques. Testing their real knowledge, we were able to check that in many cases they overestimated their knowledge on GM crops. Providing people with new information on the use of NBTs it is therefore important to allow them to make an unbiased judgment on NBTs.

Nevertheless, students showed concerns about potential risks associated with GM crops consumption and cultivation. Initially, 55% and 63% of those interviewed declared that GM food would represent a problem for food safety or for the environment. Once new information was provided from scientists, students who had concerns about food safety significantly converged to the new information received, changing their prior belief. In the case of environmental risk this process of convergence towards the new information received was lower and many students significantly diverted from the information, revealing the existence of a prejudice that did not allow them to change their original opinion i.e., people assign a higher weight to their prior beliefs. This result confirms the Grunert *et al.* (2003) finding on people's beliefs about risks as embedded in more general attitudes towards nature. This result can also be influenced by the specific target of our analysis, as millennials are considered in the literature more concerned about the environment and the ethical attributes of products (Cavaliere, Ventura, 2018). Higher environmental concern with regard to cisgenesis was also found by De Marchi *et al.* (2021), in the case of "future-oriented" consumers in Italy who perceived the technology as rather unnatural and potentially risky.

Our results also confirm De Marchi *et al.* (2022) which demonstrated that information on health-related and, especially, on environmental benefits contribute to generating a positive communication landscape around cisgenic food.

This result, in our opinion, gives an important hint to researchers about where to address communication when disseminating their findings to the general public in order to gain public support for legislative changes allowing the cultivation of crops obtained through the use of NBTs. According to these results, communication on new breeding techniques should carefully address people's concerns on potential environmental impacts to avoid consumer rejection of NMTs. Scientists should therefore disseminate their research results not only to the research arena but to policy-makers and a wider audience given the existing lack of knowledge of the general public, explaining what NBTs are and their potential benefits. In this respect, our study contributes to the literature by adding new information on a specific consumer segment (students) preferences for NBTs, providing evidence about their lack of knowledge of these techniques. The study also informs on which are the perceived potential risks and how the respondents process information to change or maintain their opinion. Our results showed that people with a higher level of knowledge on biotechnologies, such as students in the scientific area, are more likely to confirm their prior belief and in the case that they initially have a negative attitude, they do not converge to the information received showing a confirmation bias.

Knowing societal preferences is also relevant in order to implement research strategies in line with stakeholders' priorities. Addressing stakeholder priorities and preferences in the technological innovation process is considered crucial for implementing an effective commercialization trajectory for new technologies (Raley *et al*., 2016).

One main limitation of our study is the fact that our sample of university students might not be representative of the Italian student population, mainly in terms of academic background. A second limitation regards the kind of information received. Here we provided a short video on GM techniques and their potential benefits, but future research may provide new insights related to different kinds of information that could be more influential.

Although this approach provides some advantages, because it limits the possible bias from unobserved heterogeneity and provides a homogeneous population, further investigation is needed to confirm the generality of the research's result.

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APPENDIX

Tab. A.1. Beta coefficient from food safety risk.

	β Conservative	SE	β Convergent		β Divergent	
0						
1.believers			1.924***	(0.310)	-1.242**	(0.430)
1.denier			-1.389***	(0.298)	14.93	(807.2)
perceived_k			0.137	(0.211)	1.056***	(0.248)
change_k			-0.0713	(0.161)	0.566**	(0.192)
1.EU_centric			0.0459	(0.243)	-0.510	(0.294)
1.female			-0.230	(0.252)	0.251	(0.290)
_cons			0.196	(0.914)	-1.829	(1.053)
1						
1.believers	-1.924***	(0.310)			-3.165***	(0.486)
1.denier_cons	1.389***	(0.298)			16.32	(807.2)
perceived_k	-0.137	(0.211)			0.919**	(0.304)
change_k	0.0713	(0.161)			0.637**	(0.233)
1.EU_centric	-0.0459	(0.243)			-0.556	(0.356)
1.female	0.230	(0.252)			0.481	(0.358)
_cons	-0.196	(0.914)			-2.025	(1.272)
2						
1.believers	1.242**	(0.430)	3.165***	(0.486)		
1.denier_cons	-14.93	(807.2)	-16.32	(807.2)		
perceived_k	-1.056***	(0.248)	-0.919**	(0.304)		
change_k	-0.566**	(0.192)	-0.637**	(0.233)		
1.EU_centric	0.510	(0.294)	0.556	(0.356)		
1.female	-0.251	(0.290)	-0.481	(0.358)		
_cons	1.829	(1.053)	2.025	(1.272)		
N	506		506		506	

Estimates are from Multinomial logit using 506 observations. Standard Errors in parenthesis. * Indicates statistically significant at 10% level. ** statistically significant at 5% level. *** statistically significant at 1% level.

Tab. A.2. Beta coefficient from environmental risk.

	β Conservative	SE	β Convergent	SE	β Divergent	se
0						
1.believers			16.42	(616.3)	-0.00848	(0.396)
1.denier			-0.526	(0.315)	1.788***	(0.441)
perceived_k			0.343	(0.179)	0.381	(0.253)
change_k			0.191	(0.137)	0.357	(0.204)
1.EU_centric			0.517*	(0.216)	-0.407	(0.313)
1.female			-0.125	(0.223)	0.409	(0.304)
_cons			-0.783	(0.778)	-1.035	(1.105)
1						
1.believers	-16.42	(616.3)			-16.43	(616.3)
1.denier	0.526	(0.315)			2.314***	(0.475)
perceived_k	-0.343	(0.179)			0.0378	(0.287)
change_k	-0.191	(0.137)			0.167	(0.227)
1.EU_centric	-0.517*	(0.216)			-0.924**	(0.356)
1.female	0.125	(0.223)			0.534	(0.350)
_cons	0.783	(0.778)			-0.252	(1.221)
2						
1.believers	0.00848	(0.396)	16.43	(616.3)		
1.denier	-1.788***	(0.441)	-2.314***	(0.475)		
perceived_k	-0.381	(0.253)	-0.0378	(0.287)		
change_k	-0.357	(0.204)	-0.167	(0.227)		
1.EU_centric	0.407	(0.313)	0.924**	(0.356)		
1.female	-0.409	(0.304)	-0.534	(0.350)		
_cons	1.035	(1.105)	0.252	(1.221)		
N	506		506		506	

Estimates are from Multinomial logit using 506 observations. Standard Errors in parenthesis. * Indicates statistically significant at 10% level. ** statistically significant at 5% level. *** statistically significant at 1% level.

Confusion matrix Results

The confusion matrix allows relations between the classifier outputs and the true ones to be observed; indeed, it reports the classification errors. The elements in the diagonal are those correctly classified, while the elements out of the diagonal are misclassified.

TP refers to True positive, FN indicates False negative; TN denotes True negative and FP False positive. TP refers to the number of predictions where the classifier correctly predicts the positive class as positive. TN indicates the number of predictions where the classifier correctly predicts the negative class as negative. FN indicates the incorrectly predicted positive class as negative (rejected data for classes). It is the sum of the values in corresponding rows excluding the TP values. FP refers to the incorrectly identified negative values as positive. It is the sum of the values in corresponding columns excluding the TP values.

Tab. A.3. Mlogit Confusion Matrix.

		Predict		
		A	B	C
Actual	A	TRUE	FALSE	FALSE
	B	FALSE	TRUE	FALSE
	C	FALSE	FALSE	TRUE

The accuracy on the classification (ACC) and error rate are the two more common parameters used for reporting the performance of the model. The ACC is the probability of performing a correct classification:

$$ACC=TP/\ (TP+TN+FP+FP)$$
$$\text{Error rate}=(1-ACC)$$

The overall accuracy demonstrates a performance equal to 84% with an error value equal to 15.6% for

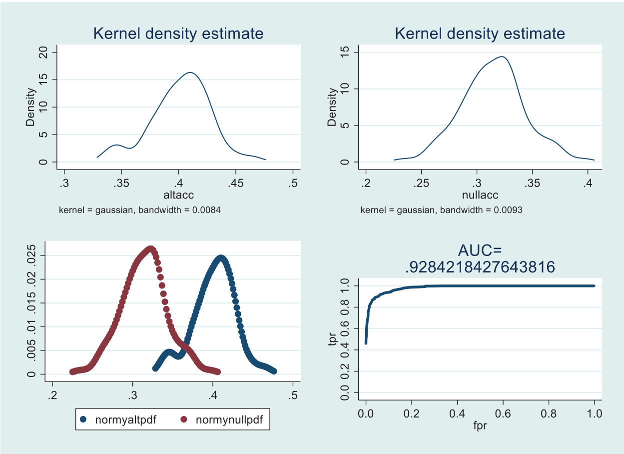
Tab. A.4. Confusion Matrix for Food Safety.

		Predicted classes					
		0	1	2	Total	FN	Overall FN
Actual	0	225	2	44	337	46	163
	1	58	8	3	12	61	
	2	54	2	110	157	56	
	Total	271	69	166	506		
	FP	112	4	47			
	Overall TP	343					
	Overall FP	163					

Tab. A.5. Confusion Matrix for Environmental risk0.

		Predicted classes					
		0	1	2	Total	FN	Overall FN
Actual	0	282	52	146	480	198	217
	1	0	0	0	0	0	
	2	12	7	7	26	19	
	Total	294	59	153	506		
	FP	12	59	146			
	Overall TP	289					
	Overall FP	217					

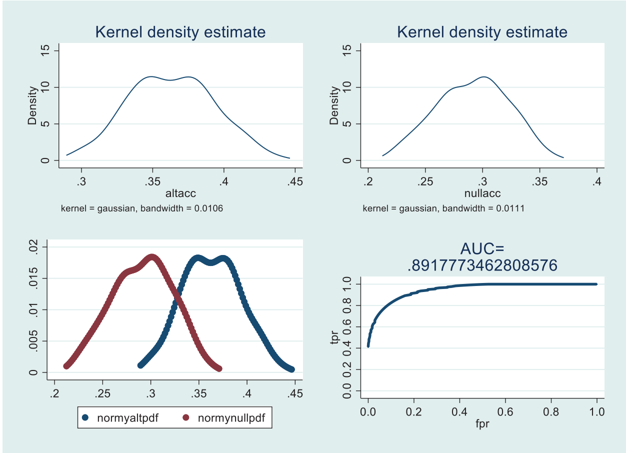
Fig. A.1. Roc curve for consumption model.



the consumption model and 57.9% with an ER of 42%. Results of the ACC, which is the probability of performing a correct classification, show a high probability for the consumption model.

To investigate the quality of the prediction in terms of sensitivity and specificity, the area under the receiver operating characteristic (ROC) curve (AUC) is also examined. Figure 4 shows the smoothed probability distributions for 100 alternative and null accuracy values by using the kernel density estimation (KDE, Gaussian kernel). The false positive rate (FPR), true positive rate (TPR), and area under the curve (AUC) come from the smooth pdfs derived from KDE (Peterson, 2010). The performance of the proposed model for consumption shows a high prediction at 92.82% in comparison to the environment, which is equal to 89.17% (Fig. 7 and 8).

Fig. A.2. Roc curve for the environment model.



Complementary material: Questionnaire

Questionnaire on the knowledge of genetic improvement techniques and attitude to consumption.

Section 1: Generalities

1) Gender
2) Age
3) Study field
4) Bachelor or master

Section 2: Attitude and risk perception about genetically modified crops

1) Do you agree with the following statement: Is food that contains ingredients obtained from genetically modified plants "safe to eat"?
   - I totally disagree
   - I disagree
   - I do not know
   - I agree
   - I completely agree
2) How would you rate the previous answer?
   - I'm not sure at all

- I'm pretty sure
- I'm absolutely sure

3) Do genetically modified crops represent a potential danger to the environment?
   - I totally disagree
   - I disagree
   - I do not know
   - I agree
   - I completely agree
4) How would you rate the previous answer?
   - I'm not sure at all
   - I'm pretty sure
   - I'm absolutely sure
5) Would you buy an apple that has not been chemically treated and in which pest resistance has been achieved through the use of biotechnology?
   - Yes
   - Only if the price is at least 10% lower than the conventional product
   - Only if the price is significantly lower than the conventional product
   - Never, under any circumstances
   - I do not know
6) How would you rate the previous answer?
   - I'm not sure at all
   - I'm pretty sure
   - I'm absolutely sure

Self-assessment of knowledge of techniques for genetic improvement of agricultural products.

7) How do you evaluate your knowledge on genetic breeding techniques?
   - 1 to 4
8) Of which techniques are you aware? (Multiple choice)
   - Crossing and selection
   - Mutagenesis
   - Assisted selection with molecular markers
   - In vitro culture techniques
   - Genome editing
   - Cisgenesis
   - Transgenesis
   - Others:
9) Which is your main information source on biotechnologies? (Multiple choice)
   - Press
   - Scientific articles
   - Television
   - Social media
   - Friends
   - None
   - Other:

Section 3: Objective knowledge evaluation

10) Is it possible to cultivate GMOs in Italy?
    - Yes
    - No
    - Yes, for not in-field experimentation
    - Yes, in field only for experimental use
    - I don't know
11) Is it possible in Italy to use animal feed containing components derived from genetically modified plants?
    - Yes
    - No
    - I don't know
12) What percentage of world maize production comes from genetically modified seed?
    > 0 – < 25%; > 25% – < 50%; > 50% – < 75%; > 75%
13) What percentage of world tomato production comes from genetically modified seeds?
    > 0 – < 25%; > 25% – < 50%; > 50% – < 75%; > 75%
14) What percentage of world wheat production comes from genetically modified seed?
    > 0 – < 25%; > 25% – < 50%; > 50% – < 75%; > 75%
15) What percentage of world soybean production comes from genetically modified seed?
    > 0 – < 25%; > 25% – < 50%; > 50% – < 75%; > 75%
16) What are the reasons that led to genetically modifying crops (multiple choice) * Check all that apply.
    - Insect resistance
    - Plant disease resistance
    - Resistance to herbicides
    - Improve the nutritional content
    - Reduce food waste
    - Reduce production costs
    - Reduce the use of fertilizers
    - Improvement of traceability
    - Promote adaptation to climate change. Safeguard biodiversity
    - Obtain varieties with superior quality characteristics
    - Other
17) Are the following statements true or false?
    - Non-GM tomatoes do not contain genes while genetically modified ones do
    - Maize always contained the same genes before it was possible to genetically modify it
    - All fresh vegetables contain deoxyribonucleic acid (DNA)
    - Brewer's yeast contains living organisms
18) Is it mandatory (according to Italian law) to indicate the presence of GM raw materials on food labels?
    - Yes
    - No

- Above a certain threshold
- I don't know

Section 4: Governance

19) Who, in your opinion, should make decisions about the possibility of producing genetically modified crops?
    - The Region
    - The State
    - The European Union
    - I don't know
20) Who, in your opinion, should make decisions regarding the labelling of genetically modified products?
    - The Region
    - The State
    - The European Union
    - I don't know
19) Decisions regarding the cultivation and labelling of GM products should be made predominantly on the basis of the opinion of:
    - Scientific experts
    - Popular consultation
    - I don't know

We proposed a short video (available upon request)

Section 5: repeated questions

20) Do you agree with the following statement: "Are foods that contain ingredients obtained from genetically modified plants "safe to eat"?
    - I totally disagree
    - I disagree
    - I do not know
    - I agree
    - I completely agree
21) How would you rate the previous answer?
    - I'm not sure at all
    - I'm pretty sure
    - I'm absolutely sure
22) Are genetically modified crops a danger to the environment?
    - I totally disagree
    - I disagree
    - I do not know
    - I agree
    - I completely agree
23) How would you rate the previous answer?
    - I'm not sure at all
    - I'm pretty sure
    - I'm absolutely sure
25) Would you buy an apple that has not been chemically treated and in which pest resistance has been achieved through the use of biotechnology?
    - Yes
    - Only if the price is at least 10% lower than the conventional product
    - Only if the price is significantly lower than the conventional product
    - Never, under any circumstances
    - I do not know
26) How would you rate the previous answer?
    - I'm not sure at all
    - I'm pretty sure
    - I'm absolutely sure

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Research article

Households' Rice Demand Response to Changes in Price, Income and Coping Strategies during Food Inflation in Nigeria: Evidence from Oyo State

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Abstract. Food price is a main driver of inflation that erodes the purchasing power of households. The study examined demand response to changes in price of rice during food price inflation in Nigeria using sampled households from Oyo State. A multi-stage sampling procedure was used to select 174 households for the study. Primary data were obtained on types of rice, frequency and quantity bought, reasons for demand, price variations and coping strategies. Descriptive statistics and Quadratic Almost Ideal Demand System (QUAIDS) that take into account the non-linear impact of income changes was used for data analysis. Over 70% of households' demand was for imported long grain rice, local brown and wet grain rice and local brown and dry grain rice. The expenditure elasticities of both local short brown wet rice (LSBWR) and imported short grain rice (ISGR) was positive and <1 indicating that they were normal and necessary food items. Strategies mainly used to cope with rice price and households' income changes include: substitution of rice with other food types, preparation of rice with other foods to reduce quantity of rice in meals and reduction of rice demand. Even though price intervention may not lead to a significant effect on rice demand, an improvement in technology will lead to reduction in the cost of rice production and eventually reduce the price of local rice, enhance high demand and encourage producers to increase production.

Keywords: consumer responsiveness, compensated elasticity, uncompensated elasticity, LSBWR, LSBDR, ISGR, ILGR, QUAIDS.
JEL codes: D01, D11, D12, D15, E31, H31, J28, R22.

HIGHLIGHTS

- Over 70% of households' still buy rice, especially the imported long-grain type during food inflation in Nigeria.
- Income elasticities of local brown wet and imported short-grain rice are positive.

- Although own-price elasticities of all rice types are negative, imported short-grain rice is highly elastic.
- Main coping strategy used by households during food inflation is substitution. Policy to increase households' income is needed to protect them from higher prices.

1. INTRODUCTION

Everyone consumes food. As a result, everyone is affected to some degree by food price changes. Economic laws have shown an inverse relationship between the prices of goods and services and the value of money in an economy. Other things being equal, as prices rise over time, a given amount of money will be able to purchase fewer and fewer goods. In the presence of inflation, a given level of households' income will buy less goods and services. Food inflation is a general increase in the prices of food or a decline of purchasing power of a given currency over time. The causes of food inflation are not unconnected with sharp and continuous decline of the value of the naira (for instance, one United States Dollar (USD) exchanging between ₦410 – ₦420 over a long period of times in Nigeria), attacks on farms, forex scarcity leading to an increase in cost of imported items like food, raw materials, and machinery with food insecurity as a major consequence. Scarcity of dollars leads to speculative product hoarding which again leads to artificial scarcity and an attendant increase in the prices of food.

Rice demand response (DR) is defined as the changes in quantity of rice consumers are willing and able to buy compared to their normal consumption patterns in response to changes in price of rice, the price of close substitutes, the price of complementary items, and household income as well as by several non-economic factors including tastes and preferences, family size, age of family members, geographic location, shopping behaviour, and lifestyle choices (Adeyonu *et al.,* 2021). In many countries of Africa, rice is a staple food and constitutes a major part of the diet. Over the past three decades, rice has witnessed a steady increase in demand and hence producing it is also gaining an important place in the food security policy of many countries (Saka, Lawal, 2009). Cadoni and Angelucci (2013), posited that rice is an essential food item for most people in sub-Saharan Africa, especially West Africa, and forms over 20% of the global calorie intake.

In Nigeria, rice is known to be the fourth most consumed food item in terms of calories (Cadoni, Angelucci, 2013) and a major component of Nigerians diet (Okunola, Bamgboye, 2016). Nigerians consume both local and imported (short and long grain) rice in different proportions. Brown rice (unrefined) is healthier than refined grains and its consumption is linked to a decreased incidence of type 2 diabetes (Sun *et al.,* 2010). The LSBWR is a whole grain mostly short and has bran and germ with about 32% moisture content compared with the LSBDR rice which contains about 10% moisture content (Arije *et al.,* 2019). Brown rice (whether wet or dry) has more nutrients and health benefits than white rice (Ologbon *et al.,* 2012). Some of the major local varieties of rice produced and consumed are: "Ofada", "Abakaliki", "Bida" and "Igbemo". Ofada rice is a short, robust brown grain with red kernels widely cultivated in all the ofada rice-producing areas of four states (Ondo, Ogun, Oyo, and Osun) in the Southwestern part of Nigeria (Danbaba *et al.,* 2011). Abakaliki Rice is the name for the local type that is grown in the Southeastern part of Nigeria and comes from Abakaliki rice mill in Ebonyi State. The polished ones come out white while unpolished ones can also come out brown. Igbemo rice is a local cultivar having bold extra-long grain with mean sphericity of 0.4 ± 0.03 indigenous to Ekiti State in Southwest Nigeria, while Bida rice are those produced in Bida town and the neighboring states in Niger State, Nigeria. Other varieties of rice produced and consumed in Nigeria include: FARO 44 released by the National Cereals Research Institute (NCRI) which is a slender long grain with mean sphericity of 0.43 ± 0.18, ITA 150, a slender long grain with mean sphericity 0.41 ± 0.04 released by the International Institute for Tropical Agriculture (IITA), and NERICA 1, a bold grain with mean sphericity of 0.48 ± 0.05 released from the West Africa Rice Development Agency (WARDA) now renamed as Africa Rice Center (Okunola, Bamgboye, 2016).

The rice (polished rice) imported to Nigeria are of different shapes (long, medium and short) but the long and short grain rice are popular. According to the International Rice Research Institute (IRR) classification, rice grain is long if it is <6.61 mm in length, medium if between 5.51 to 6.6 mm in length and short if < 5.50 mm in length (IRR, 1996). In addition, the long grain rice is cylindrically longer compared with the short grain rice which is shorter and wider.

Over the years, the rate of increase in demand for rice in Nigeria as the largest consumer of rice has been higher than its counterparts in the West Africa region (Tondel *et al.,* 2020; Okpiaifo *et al.,* 2020). Between 2011 and 2019, rice consumption in Nigeria rose from 5.6 million to 6.9 million tons (Morse, 2019). According to Erhabor and Ojogbo (2011), rice has gone beyond being just referred to as a normal good in Nigeria and has become a necessary commodity that takes an average of 21-25% of a rice-consuming household's food budget share.

Nigeria's rice production as indicated in Figure 1 rose from 3.7 million metric tons in 2017 to 4.0 million metric tons in 2018. In spite of this, only 57% of the 6.7 million metric tons of rice consumed in Nigeria annually is produced locally, leading to a deficit of about 3 million metric tons which is sourced through rice importation. To stimulate local production, the Nigerian Government banned importation of rice in 2019 with commendable research conducted to ensure a steady and reliant rice industry in Nigeria. In spite of this, rice production marginally rose from 4.9 million metric tons in 2000 to 5.0 million in 2021, leading to a deficit of about 2 million metric tons (Fig. 1) which is either imported or smuggled into the country illegally. A large proportion of studies on rice only focused on improving the supply side of the Nigerian rice industry through improved production efficacy (Shehu *et al*, 2007), increased returns (Onoja, Herbert, 2012), improved technologies (Saka, Lawal, 2009) among others, with a gap in the literature on demand response of households, response to changes in rice prices and household income during food inflation.

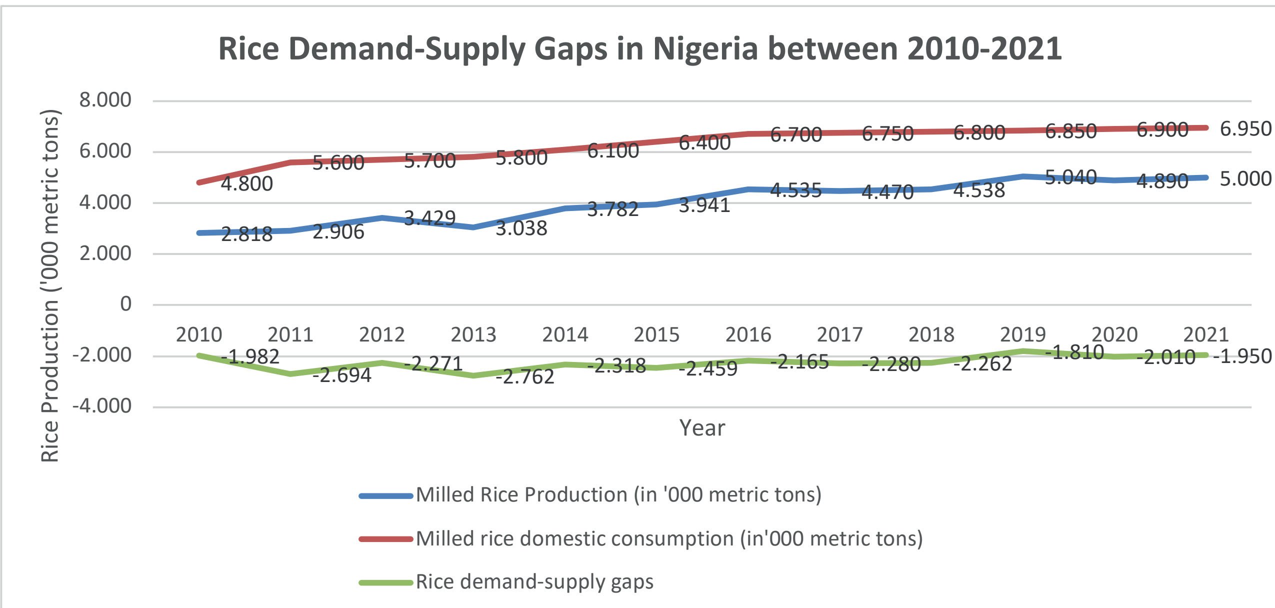
Therefore, this study attempts address the following questions: (i) What is the households' rice demand pattern during food inflation? (ii) How does households rice DR change with price and income during food price inflation? (iii) What are the various coping strategies used by households against changes in the price of rice?

To address these questions, the broad objective of the study is to assess rice demand response to price and income changes among households during a food price inflationary period in Oyo State, Nigeria. The specific objectives of this study are:

1. assess the nature and households' rice demand pattern in the study area;
2. estimate compensated and uncompensated households' elasticities rice demand in the study area;
3. identify the various coping strategies against changes in the price of rice.

The study is unique because it estimated price, income and cross-price elasticities of demand for rice types during food inflation using a complete demand system, instead of a partial demand modelling approach often adopted, for all food groups in Nigeria. To the best of our knowledge this is hard to find in the food demand literature. The estimated elasticities are important for policy purposes. The study concentrated on four types of rice [LSBDR, LSBWR, ISGR and imported long grain rice (ILGR)] that are consumed in the study area. The findings contribute not only to the existing literature on food demand but to food inflation.

Fig. 1. Trends of rice demand-supply gaps in Nigeria between 2010-2021.



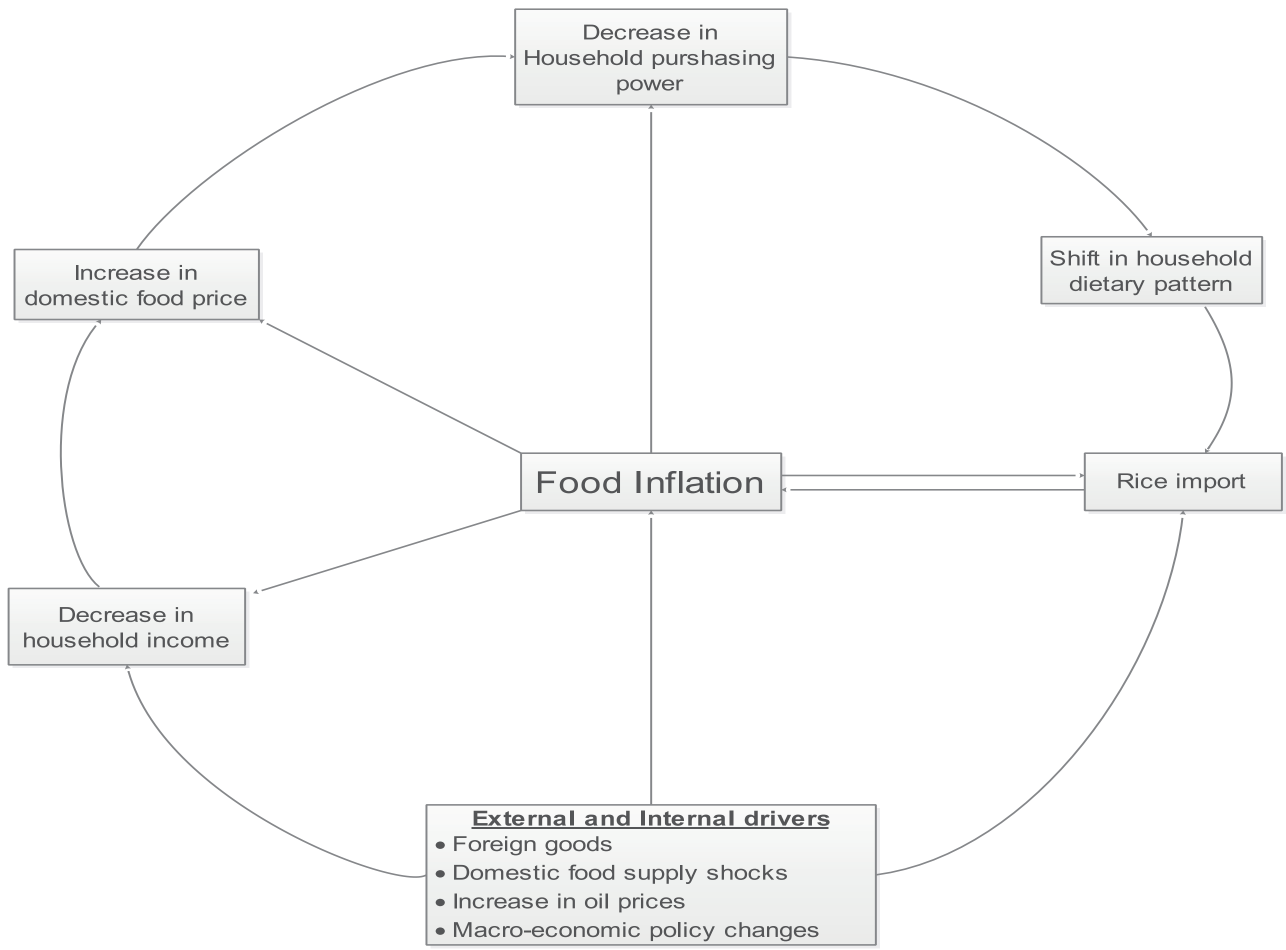
Source: Authors from USDA (2022) rice data outlook.

2. CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

Estimating household demand is similar to the evaluation of household consumption behaviour in response to price shocks and changes in income of households. The theoretical model is based on the Engel Curve Framework, which explains the relationship between household expenditure on a specific commodity and household income (Chai, Moneta, 2010). Allocation of expenditure in the household is a function of the household's demographic characteristics like size, income group, age, gender and prices. Household food demand patterns are affected by food supply, food prices (local and international food shocks) and the percentage of the household's expenditure (income) dedicated to consumption during food inflation. Food inflation is usually caused by rising domestic prices due to limited supply that is unable to meet domestic demand. Households' food habits and patterns are altered as a result of rising food prices thereby forcing households to eat less nutritious or expensive meals (Fig. 2). Rice imports are the solution to stabilize domestic rice prices and reduce food inflation. Households that dedicate a higher percentage of their total income to food are likely to experience higher food inflation since an increase in the price of a consumer basket means that more money is spent on consumption compared to those households whose proportion of money spent on food is small (Capehart, Richardson, 2008). Consumers prefer to spend all of their wealth or income on food because more is always at least as good as less and consumers are never satiated.

A good number of relevant literature studies were reviewed so as to gain adequate and proper insight into the various modes of approaches to food demand estimation. Adeyonu *et al.* (2021), examined food DR to rising food prices among farming households in Nigeria using the three waves of the General Household Survey

Fig. 2. Links between food demand response to income, prices and inflation.



(Panel) conducted between 2010 and 2016 with the use of Quadratic Almost Ideal Demand System (QUAIDs), with major findings that escalating prices result in a welfare loss of household expenditure on commodity groups such as rice, wheat, pulses, tubers and other food and non-food items. Otunaiya and Shittu (2014) in their study using this same model found the expenditure (income) elasticity of demand for some vegetables (bitter leaf and eggplant) to be negative, which is similar to the evidence from Ogundari (2014) for vegetable oil and cereals. Olorunfemi (2013), estimated the demand for food in Ondo State, Nigeria; using the QUAIDS model the research result revealed that the estimated expenditure elasticities for all food are positive and statistically significant at 5%, indicating that all the food items are normal goods and that rice, beans, yam-flour, meat, vegetable and fruits are luxury goods. However, in the study, garri, yam, bread and plantain are all necessities. Similarly, Abramovsky *et al.* (2012) estimated the demand system for Mexico using QUAIDS; Blow *et al.* (2015), also used QUAIDS to model the United State consumer expenditure data for non-durable goods. Obayelu *et al.* (2009), in their study on Cross-sectional analysis of food demand in Northern-central Nigeria used the QUAIDS model to estimate price and expenditure elasticities of six food groups (roots and tubers, cereals, legumes, animal protein, fruits and vegetables, fats and oil) consumed. The result showed that all six food groups analysed were price inelastic, income elasticity showed that animal protein consumption was most affected by income variations, while fats and oil were less so and the factors that positively affected demand for legumes, fats and oil, animal protein, cereals and roots and tubers were household size, level of education, primary occupation and access to credit.

Others past studies that have also applied QUAIDS as appropriate demand models include: Gould and Villarreal (2006) using food expenditure data from urban China, Molina and Gil (2005) applied QUAIDS to aggregate consumption data from Peru, Abdulai and Aubert (2004) on Tanzanian food expenditure data, Abdulai (2002) on the food expenditure data from Switzerland, Fisher *et al.* (2001) on the US aggregate consumption data, Moro and Sckokai (2000) on Italian food expenditure data, Banks *et al.* (1997) and Blundell and Robin (1999) on consumption goods expenditure data from the United Kingdom, Meenkashi and Ray (1999) using Indian food expenditure data.

Adetunji and Rauf (2012), investigated household demand for meat in Southwest Nigeria using the Almost Ideal Demand System (AIDS) Model. Ogunniyi, Oladejo and Akinniyi (2012) used the same model to investigate households demand for processed fruits in Abeokuta Metropolis of Ogun State, Nigeria, while Robert (2009) examined yam consumption patterns in Ghanaian urban communities with quarterly household panel data collected from four urban centres with both AIDS and QUAIDS. It was discovered by Robert that the shares of food budget that households allocated to yam generally increased during the peak harvest season and dropped during lean season across all urban centres in Ghana.

The study by Haq *et al.* (2009), employed the Linear Approximate of Almost Ideal Demand System (LA/AIDS) in estimating the own and cross price compensated and uncompensated elasticities and expenditure elasticities of food demand in Pakistan (Northwest frontier province). Their results showed all the food items were normal, while rice, fruits, meat and other food products were found to be expenditure elastic as compared to wheat, vegetables, milk and cooking oil and also that Hicksian own and cross-price elasticities move closely with the Marshallian elasticities. Ezedinma *et al.* (2006) in their study on urban household demand for meat and meat products in Nigeria used the LA/AIDS method to aggregate a portion of the data on meat and meat products namely beef, mutton/goat, chicken, fish, eggs and milk. Their results indicated that urban demand for meat products will increase significantly as incomes increases, suggesting potential market opportunities, especially for poultry. In a similar study, Taljaard (2003) used the LA/AIDS model to estimate the demand for meat in South Africa. Hayat *et al.* (2016), estimated LA/AIDS for the demand analysis of selected food commodities in Pakistan. This study based on estimated values of elasticities, found that vegetables, sugar, pulses, grains ghee and food grains are necessities while meat and milk are the luxuries. Other studies such as Haq *et al.* (2011), Aziz *et al.* (2011), Khalil and Yousaf (2012) also analysed income and price elasticities of food items with LA/AIDS from data collected in Pakistan.

Omonona *et al.* (2009), employed a two-stage LA/AIDS model to examine micro level data on household consumption of four food groups (grains, roots/tubers vegetables/fruits and meat/fish) in their study on household food demand in semi-urban and rural households in south-west Nigeria. Their study showed that aggregate food demand in the study area is inelastic to price changes, with the exception of grain and aggregate expenditure elasticities also revealed that meat/fish are luxury foods while the others are necessities. Erhabor and Ojogho (2011) applied LA/AIDS in examining the demand analysis for rice in the Edo, Delta and Lagos states area of Nigeria. The results indicated that at higher levels of income, expenditure share of rice decreased, marginal expenditure share was high for meat or fish followed by rice indicating that food demand pattern would not be substantially changed, even with an increase in future food expenditure. Canh (2008) applied LA/AIDS to calculate income and price elasticities for three different components of food categories and found that rice food and meat/fish are normal goods, while non-rice food is a luxury.

Vu (2020), applied the modified Almost Ideal Demand System (MAIDS) to estimate food demand patterns in Vietnam. The results indicated that all food has positive expenditure elasticities and negative own-price elasticities in Vietnam and demand is affected by income, price, as well as socio-economic and geographic factors.

In Egypt, Dawoud and Seham (2013), analysed the changes in food expenditure patterns over time with special emphasis on the differences between urban and rural sectors using Weighted Least Squares (WLS). It was discovered that food consumption expenditure patterns have changed over the five consecutive survey periods as a result of economic changes.

The reviewed literature revealed the gap in the empirical literature on households' rice demand response to changes in price, income and how rice consuming households cope during inflation. This study will therefore add to the existing literature on households' rice demand response to price and income through the use of the QUAIDS model as an appropriate approach. The model is an extended form of the AIDS model that approximates non-linear Engel curves in empirical analysis (Xie *et al.,* 2004).

3. MATERIALS AND METHODS

3.1. Study area

The study was conducted in Oyo State. Oyo State is located in the Southwest (SW) geopolitical zone of Nigeria; it consists of 33 Local Government Areas (LGAs) which include Akinyele, Afijio, Ibadan Northwest, Ibarapa Central among others. The state covers a total of 28,454 square kilometres of land mass and is bounded to the South by Ogun State, to the North by Kwara State and to the East by Osun State. The landscape consists of old hard rocks and dome shaped hills, which rise gently from about 500 metres in the Southern part and reach a height of about 1.219 metres a.s.l. in the Northern part. According to the 2006 census, the state population was 5,501,589 comprising 2,809,840 males and 2,781,749 females (NPC, 2006). Agriculture is the major source of income for the greatest number of the people and the mainstay of the economy. Climate in the state favours the growth of food crop such as yam, cassava, millet, maize, rice, plantain, rice, palm tree, cashew among others. Three vegetation regions are identified, namely: forest, savannah and derived savannah. Ibadan/Ibarapa zone falls within the forest region while Ogbomosho and Oyo zones are in the derived savannah region.

The data collected were on the demographic characteristics (sex, age and educational level, household size, and household income) from household heads or their representatives where the heads were not available. Data were also collected on the households' rice consumption with respect to the types, frequency, quantity, price and expenditure on rice consumed by the households per week.

3.2. Sampling Procedure

A multi-stage sampling technique was employed in the selection of the sample in this study. The data were collected in 2021. The first stage involved random selection of five (5) LGAs which are Ibadan North, Ibadan Northeast, Egbeda, Ogbomosho South and Oyo East out of the thirty-three LGAs in the state. The second stage involved the random selection of three (3) wards each out of the five (5) LGAs. The final stage involved the random selection of 12 households from each selected ward which gave a total of 180 households, out of this, 174 were found useful for the study and the remaining 6 discarded due to incomplete information. Data were collected with the aid of a structured questionnaire and administered through the assistance of trained enumerators.

3.3. Analytical Techniques

The data obtained from the field were analysed using various analysis methods which include: Descriptive Statistics, Likert Scale, QUAIDS. Households' responses to price (own-price and cross-price of rice demand for local, imported and both local and imported rice) and income changes are estimated in the form of expenditure and price elasticity through the use of QUAIDS Model following Banks *et al.* (1997). In QUAIDS, expenditure share equations are quadratic functions of the logarithm of total expenditure. The model was considered appropriate for this study because it takes into account mutual interdependence of a number of commodities in consumers' budget decisions and makes demand projections after taking into account income distribution and variations in some of their demographic characteristics (Mittal, 2010). This model is expressed in Equation (1)

$$w_i = \alpha + \sum_{j=1}^{K} \gamma_{ij} \ln p_j + \beta \ln\left\{\frac{m}{P(p)}\right\} + \frac{\lambda_i}{b(p)}\left[\ln\left\{\frac{m}{P(p)}\right\}\right]^2 + \sum_{j=1}^{K} \partial_{ij} D_{st}^{h} + \varepsilon_i \quad (1)$$

Where:
α, β, γ, λ – parameters estimated
γ_{ij} - estimated coefficient of prices for rice.
w_i - Household expenditure share of i^{th} type of rice.
w_1 - expenditure share on LSBWR
w_2 - expenditure share on LSBDR
w_3 - expenditure share on ISGR
w_4 – expenditure share on ILGR
p – Stone's price index
ln p_j = nominal price of the j^{th} food commodity
ln m = log of household's total expenditure on all food in the demand system (₦/month)
D^{h}_{st} = Demographic variables:
D_1 = Age of household head (years)
D_2 = Household size (no of persons)
D_3= Sex of household heads (1 if male, otherwise 0)
ε_i = Error term

The Marshallian uncompensated price elasticities were calculated from:

$$e^{u}_{ij} = \frac{\mu}{w_i} - \delta_{ij} \quad (2)$$

The Hicksian or compensated price elasticities were calculated as follows:

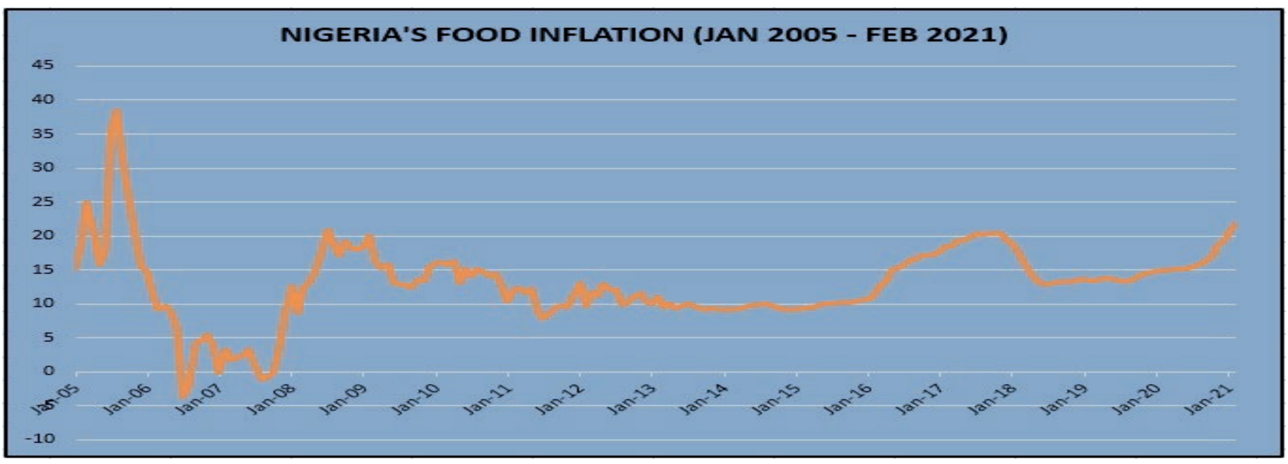
$$e^{c}_{ij} = e^{u}_{ij} + w_j e_i \quad (3)$$

4. RESULTS AND DISCUSSION

4.1. Stylist Fact about Food Inflation in Nigeria

Food inflation in Nigeria averaged 11.6% from 1996 until 2019, reaching an all-time high of 39.5% in September 2001 and a record low of -17.5% in January 2000 (Trading Economics, 2022). The country is still struggling with rising food prices, because it largely depends on agricultural imports, especially grains to meet the demand gap as indicated in Fig. 1. Inflation in Nigeria has been in double-digits since 2016 (Fig. 3), impacted by food-related pressure and currency weakness. The country's inflation rate is higher than other African countries (Fig. 4). Further acceleration of food inflation rate may not be unconnected to closure of land borders in 2019, the outbreak of the COVID -19 pandemic in 2020, conflict between farmers and herders, climate change and changes in monetary policy (Ezeanyeji *et al.,* 2021; Bello, Sanusi, 2019; Moser, 1995). The rapid changes in food prices affect consumers whose income remains unchanged, thereby affecting food items in their budget. Food inflation in Nigeria which has been on average 12.2% from 1996, rose as high as 22.9% more expensive than in 2020 and 39.54% in September 2021 (NBS, 2022). In 2014, according to the National Bureau of Statistics, a 50 kg bag of rice averaged ₦10,000. At the end of June 2020, a 50 kg bag of rice went for an average of ₦26,000. In many parts of Nigeria, in December 2021, a 50 kg bag of short-grain foreign rice sold for ₦24,000, and long-grain between ₦26,000 and ₦27,000; while local rice sold for ₦23,000 compared to January 2022, when a 50 kg bag of local rice was sold for between ₦24,000 and ₦25,000

Fig. 3. Trends of average food prices in Nigeria between 2005-2021**.**



Source: Compiled data from the National Bureau of Statistics, Nigeria from various issues. Available at https://nairametrics.com/2021/03/18/food-inflation-rate-in-nigeria-surges-to-highest-in-over-15-years/.

and a 50 kg bag of short-grain imported rice sold for between ₦30,000 and ₦32,000 (NBS, 2022).

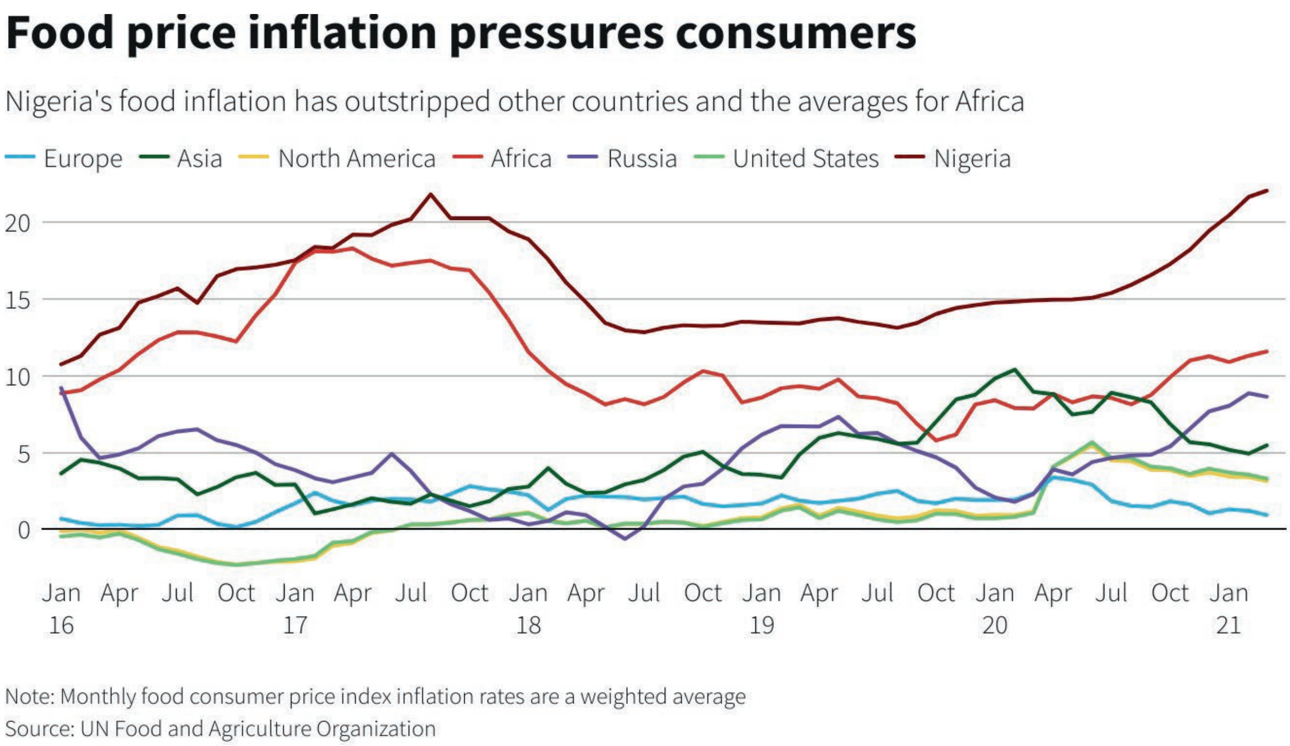
4.2. Households Rice Demand and Income Elasticity

Findings from the study revealed that a larger proportion (70.1%) of households had per capita weekly rice demand of between 1-3 kg ($\bar{x}$= 3.10 kg, Standard Deviation (SD) ±1.85 kg) of ILGR, 50% per capita weekly ISGR demand of 1-3 kg ($\bar{x}$= 4.35 kg, SD ± 2.67 kg); 70% per capita weekly lSBWR rice demand of 1-3 kg ($\bar{x}$= 3.30 kg, SD ± 1.42 kg) and 73.5% had per weekly LSBDR demand of 1-3 kg ($\bar{x}$= 2.79 kg, SD ± 1.32 kg). This by implication, shows that many households' demand for both long grain imported rice, LSBWR as well as LSBDR fell during food inflation in the study area.

Price and households' income variations have been significant determinants of rice demand. Income and price elasticity provide valuable information on how consumers react to changes in price and income. The income elasticities (IE) articulates the change in quantity demanded of the food item due to change in household income. The results in Table 1 of the QUAIDS model revealed that expenditure terms (beta) are statistically significant in all four expenditure share equations. Results showed that IEs of LSBWR, ISGR and ILGR were significant. LSBWR and ISGR were found to be normal and necessities for household consumption with positive coefficients of less than one. This result is consistent with that of Onyeneke *et al.* (2020) and Zhou *et al.* (2015) who posited that most primary food products such as rice are normal and necessities. The estimated result showed that the IE of LSBWR is 0.09, indicating that a 10% rise in households' income stimulates LSBWR demand by 0.9%. This result however, disagrees with Ogunleke and Baiyegunhi (2019) who found that, as income increases, demand and consumption of local brown rice decreases in South-western Nigeria but corroborates the classical microeconomics that demand is a positive function of income for normal goods.

Similarly, the IE of ISGR of 0.15 indicates that a 10% rise in households' income leads to 1.5% increase in demand of ISGR. ILGR appears to be an inferior item during food inflation since the expenditure elasticity of demand for this type of rice is -0.08. This means that if households' income increases by 10%, expenditures on ILGR are likely to reduce by 0.8%. It is not surprising that the study found an inverse relationship between demand for ILGR and income in the study area. The

Fig. 4. Food inflation trends in Nigeria between 2016-2021.



Source: UN-FAO (2021).

possible explanations for this could be that households with higher income probably want to consume more of other types of rice like the LSBDR as a result of the higher nutritional quality as maintained by Gyimah-Brempong *et al. (*2016) and Ayinde *et al.* (2013) compared with ILGR.

The gamma-parameters in the model captured the responsiveness of demand to variations in relative prices, including both the own price of good i and the prices of other goods j. Most of the price effects are significantly different from zero at the 5% significance level. This suggests that there is much quantity response to movement in relative prices. For instance, a change in the price of LSBWR leads to a systemic change in the expenditure share of LSBWR, ISGR and ILGR by 39% 65%, and 33% respectively. Also, the quadratic expenditure terms (lambda) are similar to the linear expenditure term with a minor difference. The lambdas regulate the effects of the second order coefficient on budget shares (thus allowing for nonlinear Engel curves) whereas the beta parameters only regard expenditure and budget shares as a linear relation. Three of the lambda parameters estimates are statistically significant. This confirms the relevance of the quadratic term extension of the linear AIDS.

The coefficient of sex is a negative and significant factor that influences expenditure share of LSBDR. This indicates that the fewer the male members in the household, the greater the expenditure share on LSBDR. This is a noteworthy finding considering the core role women play in household food choice (PrOpCom, 2009), and is in agreement with the study of Tomlins *et al.* (2007) who stated that sex is one of the factors that influence households' expenditure share on rice.

Household size is negative and significantly related to ISGR indicating that, the smaller the household size, the higher the expenditure share on ISGR. This result is consistent with Almas *et al.* (2019) who found that household size negatively relates to food consumption expenditure. Contrary to this, the coefficient of age of the household heads was positive and significant to expenditure share for the ISGR indicating that as age increases, the expenditure share on ISGR increases.

The above results suggest that the quantity of rice bought is a function of relative price and income movement during food inflation in the study area.

4.3. Own-price elasticity for rice types

Compensated price elasticity shows a change in quantity demand because of a change in prices by capturing only the substitution effect. Uncompensated elasticity, on the other hand, captures both the substitution as well as the income effect. The uncompensated own price and cross elasticity matrix is presented in Table 2, while the compensated own price and cross elasticity matrix is shown in Table 3. The own price elasticities are shown in bold figures along the major diagonal in Tables 2 and 3. The uncompensated and compensated own-price elasticities are negative for all rice types, this is consistent with consumer demand theory. The nega-

Tab. 1. Estimated Parameters of QUAIDS with Demographic Variables.

Budget Share(ཡ)	Intercept (α)	Commodity Price				Estimated Coefficient		Household Demographics		
		LSBWR	LSBDR	ISGR	ILGR	Estimated Expenditure	Estimated Price	Sex	Age	Household Size
LSBWR	3.0663** (1.2914)	3.9603 (3.4811)				0.0910** (0.0369)	1.0559** (0.4189)	0.0037 (0.0071)	-0.0004 (0.0005)	0.0053 (0.0036)
LSBDR	-0.3097 (-0.8310)	-0.7969 (1.3793)	0.3157 (0.6755)			-0.0265 (0.0282)	-0.2145 (0.3065)	-0.0174* (0.0095)	-0.0004 (0.0004)	0.0025 (0.0033)
ISGR	-3.9136** (1.5538)	-6.5219 (4.3867)	1.0798 (1.8316)	10.4689 (7.0521)		0.1467*** (0.0509)	-1.6795*** (0.5229)	0.0006 (0.0113)	0.0016** (0.0007)	-0.0094* (0.0055)
ILGR	2.1571* (1.2184)	3.3586 (2.1999)	-0.5986 (1.0682)	-5.0268 (4.1342)	2.2668 (2.7778)	-0.0822* (0.0439)	0.8381* (0.4531)	0.01319 (0.0151)	-0.0008 (0.0007)	0.0015 (0.0057)
Rho (demographic effects on expenditures)								169.6599	10.9158	-61.9932

Statistical level of significance is denoted as *, **, *** for 10%, 5%, and 1% respectively, values in parenthesis are standard error.
LBWR – Local Short Brown Wet Rice, LSBDR – Local Short Brown Dry Rice, ISGR – Imported Short Grain Rice, ILGR – Imported Long Grain Rice.
Source: Author's calculation from the QUAIDS model (2021).

tive own price elasticities indicate that an increase in the price of rice results in a decrease in its demand. LSBWR, ISGR and ILGR are relatively own price elastic, while LSBDR is own price inelastic. This is in agreement with Hoang (2018) and Obalola *et al.* (2021) whose findings showed that demand for rice with respect to prices is relatively inelastic compared to other foods. ISGR is highly elastic with own price elasticity of -1.92, suggesting that when the price of ISGR increases by 1% its demand will reduce by 1.92%.

The uncompensated own-price elasticity of LSBWR showed that a 1% fall in LSBWR price would stimulate an increase of 1.16% in demand (Tab. 2). Where the substitution effect is 1.05% (Tab. 1), it means that an increase of 1.16% in LSBWR demand due to a 1% price reduction had a 1.05% pure price effect, and the income effect of a 1% price fall on LSBWR demand was 0.11% (that is, 1.16-1.05%). A 1% reduction in rice price might raise income per capita by 1%, which would raise demand by 1.25% (that is, 1.16 + 0.09%). However, an increase in per capita income would signify a move in the local rice (brown and wet) demand curve that would usually lead to an upsurge in LSBWR prices (Tab. 1, 2, 3).

4.4. Cross-price elasticity

The compensated price elasticity measures the strength of the pure substitution effects on consumption of the rice types under consideration. The compensated price elasticity assumes that the household has been compensated with income to keep the household utility constant. The estimates reveal the substitutability and complementarity effects. Negative cross-price elasticities show complementarity, while positive cross-price elasticities indicate substitutability. It is worth noting that the increase in price of one commodity will result in an increase in the demand for that commodity's substitutes and a decrease in the demand for its complements. Cross-price elasticity less than 1 indicates that there is weak response of the rice type to changes in the price of other types of rice.

The uncompensated cross-price elasticity results show positive cross-price elasticity of LSBWR to LSBDR, indicating that LSBWR price and LSBDR demand change in a similar direction. So, it can be established that a 10% fall in LSBWR price would decrease household demand for LSBDR by 3.0% (Tab. 2). The results of LSBWR to LSBDR cross-price elasticity (compensated), which is the change in LSBWR price on LSBDR demand, showed that demand for LSBDR would reduce by 4.1% with a 10% reduction in LSBWR price, while effect of LSBWR price on ISGR implied that demand for ISGR would increase by 25.9% with a 10% rise in the price of LSBWR and demand for ILGR would reduce by 32.3% with a 10% reduction in LSBWR (Tab. 3). This finding is similar to Gyimah-Brempong and Kuku-Shittu (2016) who found that both local and imported rice are complements and characterized by low substitutability (Demont *et al.*, 2013).

4.5. Households Coping Strategies on rice demand during food inflation

Huge, impulsive and unanticipated increases in food prices force people to adjust quickly. Consumer purchasing power reduces and households are pressed closer to or below the poverty line. Results of how households cope in their rice demand response to changes in price and income presented in Table 4 revealed substitution of rice by other grain crops as the predominant strategy used to

Tab. 2. Uncompensated (Marshallian) Price Elasticity Matrix.

	LSBWR	LSBDR	ISGR	ILGR
LSBWR	**-1.1619** (4.0414)	0.3025 (3.1148)	-3.0955 (3.0093)	2.7116 (2.6057)
LSBDR	0.3590 (4.1948)	**-0.2998** (5.3122)	-3.0730 (3.7042)	0.5577 (3.2456)
ISGR	-0.8732 (0.8829)	-0.5895 (0.8058)	**-1.9270** (1.4130)	0.7510 (1.0856)
ILGR	0.8408 (0.7541)	0.2148 (0.6975)	-0.6074 (1.0751)	**-1.2057** (1.2138)

Note**:** Values in parentheses are standard error, LSBWR – Local Short Brown Wet Rice, LSBDR – Local Short Brown Dry Rice, ISGR – Imported Short Grain Rice, ILGR – Imported Long Grain Rice.
Source: Author's calculation from the QUAIDS model (2021).

Tab. 3. Compensated (Hicksian) Price Elasticity Matrix.

	LSBWR	LSBDR	ISGR	ILGR
LSBWR	**-1.0565** (4.0414)	0.4131 (3.1107)	-2.5863 (3.0074)	3.2297 (2.6147)
LSBDR	0.5743 (4.1975)	**-0.4593** (5.3060)	-2.3386 (3.738)	1.3049 (3.2628)
ISGR	-0.7548 (0.8813)	-0.5018 (0.8044)	**-1.5966** (1.4116)	-0.3400 (1.0872)
ILGR	0.9235 (0.7534)	0.2761 (0.6964)	-0.3250 (1.0692)	**-0.8747** (1.2168)

Note**:** Values in parentheses are standard errors, LSBWR – Local Short Brown Wet Rice, LBDR – Local Short Brown Dry Rice, ISGR – Imported Short Grain Rice, ILGR – Imported Long Grain Rice.
Source: Author's calculation from the QUAIDS model (2021).

cope during food inflation ($\overline{x}$= 2.68), followed by preparation of other food types such as beans, spaghetti alongside with rice to reduce quantity of rice being consumed ($\overline{x}$= 2.49), outright reduction in the quantity of rice consumed ($\overline{x}$= 2.45).These findings are consistent with other past studies such as Kodithuwakku and Weerahewa (2011) who found that most households had to substitute their food to local products to cut down consumption during the times of food price hikes in Sri Lanka.

5. CONCLUSION AND RECOMMENDATIONS

Food inflation has been on the increase for some time in Nigeria and the situation is getting worse especially after the COVID-19 outbreak in 2019. The main thrust of this paper is therefore to look at the household demand responses to changes in prices of one of the most important foods consumed by almost everyone in the country (rice) and households' income using data collected from Oyo State. The study analysed the data with the use of QUAIDS. Results show that all own price elasticities are negative, which suggests that an increase in the price of any of the commodities results in a decrease in demand for that particular commodity. The positive expenditure elasticities of LSBWR and ISGR imply that these are normal and necessary foods, indicating that expenditures on food items rise with increase in households' income. This is consistent with the consumer demand theory. Cross-price elasticities among rice types showed weak substitution effects of a price change. It was also observed that demand for LSBWR and ISGR have positive expenditure elasticities of less than 1, indicating they are normal and necessary food, while that of LSBDR and ILGR has negative elasticity values showing that they are inferior food. Households prefer the imported to locally produced rice due to its perceived greater ease of preparation.

Based on the findings of this research, the following recommendations have been put forward:

1. Because rice is one of the main foods consumed by households in the study, an increase in price of this commodity is not desirable especially by those with a low income. Any policy that aims to reduce import tariffs and other taxes to lower domestic prices and increase household total income is essential to protect the low-income population from higher prices.
2. It is important that the Nigerian government rethink its land border policy of 2018 with Benin, Togo, Niger, Cameroon and Chad affecting staple food commodities like rice. This is important because enforcement of the policy has not really been able to solve the problem but has led to rising food inflation thereby reducing the relative purchasing power of households as indicated in Figure 2.
3. Adequate policy framework aimed at reducing the cost of production and increasing supply of local rice should be pursued as this will also invariably enhance demand for local rice by households as rice was estimated to be own-price inelastic.
4. Adoption of innovative practices should be encouraged that will cause a reduction in production costs

Tab. 4. Coping Strategies used by households on demand for rice during food inflationary period.

Strategies	SA Frequency	A Frequency	D Frequency	SD Frequency	Mean	Rank
Substitution of rice by other grain crops	124	240	80	23	2.68	1
Preparation of other food types such as beans, spaghetti alongside with rice to reduce quantity of rice being consumed	124	189	82	39	2.49	2
Outright reduction in the quantity of rice being consumed	92	207	92	36	2.45	3
Consumption of other different types of less costly rice	80	159	154	24	2.40	4
Reduction in non-rice and non-food expenditure to maintain quantity of rice consumed	140	117	118	41	2.39	5
Restriction of rice consumption by adults in order to feed small children	58	147	140	33	2.34	6
Reduction in the amount spent on other types of food consumed	88	126	1467	37	2.28	7
Reduction in the frequency of rice being cooked and consumed	96	150	96	52	2.26	8
Reduction in ration of rice being served to household members	80	114	90	71	2.04	9
Suspension of rice consumption in the house	108	42	144	61	2.04	10
Purchasing consumed rice on credit	56	81	140	63	1.95	11
Taking out a loan to purchase rice	81	43	23	14	1.75	12

Note: SA, A, D and SD means Strongly Agree, Agree, Disagree and Strongly Disagree respectively.
Source: Households field survey by authors (2021).

and invariably encourage farmers to produce more rice, leading to increasing supply.

One of the limitations of this study is that evidence from data sourced from household heads may not reflect the experiences of individual member of all households in Oyo State, nor all types of rice consumed within the state. We do not make any attempt to analyse, for example, how the analysis is affecting the homeless population, households across the different LGAs. We acknowledge these drawbacks, as well as recognizing that behind the data we used are millions of households and other types of rice beyond the four in this study.

Future research studies can (i) compare households' rice demand response to changes in price, income and coping strategies across LGAs of the selected state, compare the selected state with other states within the SW, or states from other geopolitical zones with more other types of rice consumed by households, (ii) analyse dynamics of households' rice demand response to changes in price and income using longitudinal household survey data such as the Living Standards Measurement Study (LSMS) dataset and (iii) analyse rice demand response to changes in price, income and coping strategies among the homeless population.

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Research article

Analisi storica delle rese agricole e la variabilità del clima: analisi dei dati italiani sui cereali

Historical crop yields and climate variability: analysis of Italian cereal data

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Abstract. Climate change is impacting on the agricultural sector in several ways, and the effects on yields are generally among the most observable ones. Open fields crops, such as cereals, are very vulnerable to climate change. We study the historical data on yields of main cereals, namely barley, maize, oats, rice, rye, wheat, to conclude on the long run impacts of temperature and precipitation, over the period 1920-2015. Yields are found to be inversely correlated with temperatures and positively with precipitation, in both cases the relationships are non-linear, as expected.

Keywords: climate change, cereals, detrendisation.
JEL Codes: Q11, Q18, Q54.

HIGHLIGHTS:

- Climate change is challenging the Italian cereal sector.
- We quantify the impacts of climate change on yields levels and variability.
- Increased temperatures and reduced rainfall are detrimental for cereals yields.
- Risk management strategies are more and more relevant.

INTRODUZIONE

I cambiamenti climatici hanno notevoli impatti non ancora del tutto evidenziati, sebbene la loro rilevanza sia sempre più un argomento approfondito. Gli effetti di questo fenomeno sono evidenti sulle rese agricole, oggetto del presente studio. L'attenzione crescente posta all'aleatorietà del settore agricolo a causa del decorso meteorologico è dimostrata dalla notevole presenza di studi ed elaborati (Schlenker, Roberts, 2006; Finger, 2010; Kim, Moschini, 2018), che perseguono un obiettivo comune: comprendere come il clima influenzi il comparto agricolo.

L'agricoltura risulta gravemente compromessa da tale tematica ed è identificata come il settore più sensibile e vulnerabile al cambiamento del clima

(Rowhani *et al.*, 2011; Trnka *et al.*, 2016; Avanzini *et al.*, 2014; Agnolucci, De Lipsis, 2019). Alcune conseguenze negative già osservate (e.g. variazione quantitativa delle rese, riduzione della biodiversità, alterazione dei cicli produttivi), probabilmente si intensificheranno in futuro, così da compromettere la produzione agricola in molti Paesi (Peltonen-Sainio *et al.*, 2010; Sarker *et al.*, 2012; Challinor *et al.*, 2014). Per queste motivazioni occorre approfondire tali dinamiche con ulteriori studi per anticipare sfide future come l'adattamento ai cambiamenti climatici (modificazioni dei sistemi colturali per fronteggiare l'acuirsi degli impatti del clima) e interpretare le trasformazioni strutturali del settore primario (Cabas *et al.*, 2010; Ray *et al.*, 2015; Kim, Moschini, 2018).

La maggioranza degli studi individuati in letteratura ha analizzato gli effetti del clima sulle rese agricole a livello mondiale (Furuya, Koyama, 2005; Ray *et al.*, 2015) o in alcune Nazioni (e.g. Africa, India, America, Australia) (Thornton *et al.*, 2009; Barnwal, Kotani, 2013; Gaudin *et al.*, 2015; Fletcher *et al.*, 2020), rivelando che gli impatti del decorso meteorologico sono probabilmente similari nei diversi territori esaminati.

L'obiettivo dell'articolo è fornire un contributo per caratterizzare le rese delle principali coltivazioni dell'Italia. I cereali rivestono un ruolo centrale nell'agricoltura italiana, sia in termini di consumo annuo, sia per quanto riguarda la domanda delle industrie agro-alimentari.

I principali cereali coltivati in Italia sono il frumento (nella varietà durum e in quella aestivum), il mais, l'orzo, il riso, l'avena, il sorgo e la segale. Il frumento duro riveste un primario interesse nel nostro Paese, grazie alla diffusa presenza di industrie molitorie. La sua coltivazione è localizzata in particolare nell'Italia meridionale (soprattutto in aree caratterizzate da carenza idrica, nelle quali non vi sono alternative colturali). Secondo l'ultimo report dell'Istat (2021) sul settore agricolo, nel confronto tra il 2010 e il 2020, il peso dei cereali sui seminativi (in termini di superficie agricola utilizzata) passa dal 51,9% al 45,9%. Il frumento duro aumenta la sua incidenza sul complesso delle superfici cerealicole, passando dal 36,9% al 40,3%. Un discreto incremento caratterizza anche il frumento tenero (dal 15,8% del 2010 al 16,7% del 2020), l'orzo (dal 7,8% all'8,8%) e il riso (dal 7,1% al 7,6%). La coltivazione del mais, al contrario, incide sempre meno sul totale dei cereali: dal 26,7% al 20,1%. Fra i cereali minori l'avena (dal 3,7% al 3,4%) e la segale (rimasta sostanzialmente invariata) rivestono importanza per la cerealicoltura italiana.

Dando un'occhiata alle annate precedenti, risulta che queste siano caratterizzate da continue flessioni (di intensità variabile) dovute soprattutto alle condizioni climatiche avverse, alle basse quotazioni e alle conseguenti riduzioni dei margini di profitto sui costi fissi delle coltivazioni. Da un report dell'Istat (2019) si evince che i cambiamenti climatici dell'ultimo decennio hanno condizionato la redditività del settore agricolo. Le perdite di raccolta dovute a calamità naturali hanno assunto, negli ultimi anni, un carattere ricorrente. Varie produzioni ne sono state interessate, ad esempio il mais nel 2015 (-22,2%) e nel 2012 (-19,4%), il frumento duro nel 2017 (-16,4%) e nel 2009 (-29,4%).

Per le ragioni esposte, i cambiamenti climatici stanno influenzando, seppur lentamente, gli imprenditori agricoli ad aumentare il ricorso agli schemi assicurativi. Tra gli strumenti di gestione del rischio, un'opportunità strategica è rappresentata dal Fondo di mutualità nazionale sulle avversità catastrofali (Fondo MeteoCAT), previsto nella Pac 2023-27. In questo modo viene fornita alle aziende agricole una copertura dai danni alle produzioni causati da gelo e brina, siccità ed alluvioni.

Una valida alternativa sono le assicurazioni indicizzate, le quali permettono un'adeguata gestione contro le diminuzioni delle rese agricole derivanti da variabili, quali le precipitazioni e le temperature. A tal proposito sono essenziali sia i dati meteorologici storici (per una valutazione dei rischi associati agli accadimenti passati), sia i dati meteorologici previsionali (così da poter prevedere eventuali avversità climatiche). In una visione di lungo periodo, in considerazione dell'acuirsi del cambiamento del clima, il monitoraggio dei dati meteo-climatici potrà permettere una gestione efficiente dei rischi del comparto agricolo.

In questo articolo viene presentata un'analisi del comparto cerealicolo nazionale. Il contributo del lavoro è quello di evidenziare come le dinamiche meteo-climatiche di lungo periodo abbiano influenzato i cambiamenti di lungo corso delle rese agricole nel comparto cerealicolo. Nello specifico sono stati esaminati gli andamenti di temperature, precipitazioni e rese nel settore cerealicolo italiano (avena, frumento, mais, orzo, riso, segale) per il periodo 1920-2015. Nella prima sezione dell'elaborato è riportata una rassegna scientifica di alcuni lavori pubblicati, riguardanti l'argomento in esame. Nel secondo paragrafo sono descritte le variabili considerate, il modus operandi selezionato per l'analisi e i modelli econometrici utilizzati; nel terzo ci si concentra sulla presentazione e sul commento dei risultati ottenuti e infine nell'ultimo sono indicate delle considerazioni critiche sul fenomeno in questione con indicazioni di policy.

1. EXCURSUS SULLA LETTERATURA RESE-CLIMA

Ker and Goodwin (2000) e Hennessy (2009) hanno evidenziato le caratteristiche principali delle rese agricole. Gli studi indicano due proprietà fondamentali: *negatively skewed distribution* e *long left tail*. Una distribuzione con asimmetria negativa (*negatively skewed distribution*) presenta la media aritmetica inferiore della mediana, a sua volta minore della moda (μο>μe>μ); questo genera una coda alla sinistra della media (*long left tail*), che si estende verso i valori più negativi. Sia a livello concettuale che pratico, tale condizione proviene dall'eterogeneità delle condizioni di coltivazione; gli appezzamenti (di conseguenza anche le rese che ne derivano) differiscono nello spazio per molteplici cause (e.g. vincoli biologici, variazioni del clima e del suolo, utilizzo di tecnologie diverse).

Mentre i sopraccitati autori hanno delineato la forma delle distribuzioni, Finger (2010) ha posto l'attenzione sull'identificazione e l'eliminazione delle tendenze nelle serie temporali dei dati sulle rese, step essenziale per molte applicazioni in economia agraria. Non tenere adeguatamente conto della tendenza può indurre un errore di tipo I[1] o II negli studi che esaminano la normalità delle rese agricole. Ker and Goodwin (2000), indicano l'utilizzo del metodo di stima non parametrica del kernel per ottenere le densità di resa delle colture. Lo studio degli impatti del clima sulle rese agricole è svolto da almeno mezzo secolo (Black, Thompson, 1978; Furuya, Koyama, 2005; Finger, 2010), analizzando gli effetti delle temperature e delle precipitazioni in diversi contesti (Thornton *et al.*, 2009; Rowhani *et al.*, 2011; Gaudin *et al.*, 2015; Agnolucci, De Lipsis, 2019).

Gli aspetti maggiormente trattati riguardano gli effetti delle temperature e delle precipitazioni sul livello e sulla variabilità delle rese agricole. La letteratura indica che l'incremento delle temperature e il decremento delle precipitazioni siano potenziali cause della riduzione del livello delle rese (Schlenker, Roberts, 2006; Cabas *et al.*, 2010; Kim, Moschini, 2018; Lamonaca *et al.*, 2021), la cui variabilità (Briche *et al.*, 2014; Challinor *et al.*, 2014; Ray *et al.*, 2015) è ascrivibile all'aumento delle temperature e alla diminuzione delle precipitazioni (questi risultati sono riassunti nella Fig. 1).

Nella rassegna della letteratura, riportata in Tabella 1, non sono presenti contraddizioni nei risultati raggiunti dai vari studi, sebbene riguardanti sia colture cerealicole (nella maggior parte dei casi), che colture arboree, leguminose e ortive, nonché territori con notevoli differenze di sviluppo (e.g. Africa, America, Australia, Europa, India), a riprova della generalità dei risultati.

1.1 Caso studio: l'Italia

L'analisi degli impatti climatici sul comparto agroalimentare italiano è stata svolta, nella maggior parte dei casi, a livello regionale o per aree geografiche ancor più circoscritte (Ferrara *et al.*, 2010; Campiglia *et al.*, 2015; Zhu *et al.*, 2016; Mereu, *et al.*, 2021). Molti dei contributi scientifici reperibili a riguardo, si focalizzano su colture specifiche (e.g. frumento, mais, olivo, vite), confrontano varietà, impostando un'analisi d'impronta prevalentemente agronomica (Campiglia *et al.*, 2015; Orlandi *et al.*, 2020).

Ad esempio in Ferrara *et al.* (2010) vengono analizzati gli impatti del clima sul frumento coltivato nel Sud Italia; mentre nel lavoro di Zhu *et al.* (2016) si discute riguardo le modificazioni del sistema di coltivazione della vite realizzata in Toscana, in seguito ai cambiamenti meteorologici. Un aspetto comune di tutti i contributi scientifici considerati può essere così riassunto: i sistemi agricoli stanno andando incontro ad una aumentata variabilità delle produzioni con una tendenza alla riduzione delle rese per molte specie coltivate (Ferrara *et al.*, 2010; Zhu *et al.*, 2016; Orlandi *et al.*, 2020).

Risulta necessario poter avere una disamina generalizzata del problema, che coinvolga l'intero territorio nazionale e consideri differenti colture. Queste sono le motivazioni che hanno indirizzato il seguente studio a focalizzarsi sulla tematica a livello nazionale, descrivendo quale sia la macro-dinamica che coinvolge l'Italia.

2. DATI E METODOLOGIA APPLICATA

2.1 Rese agricole

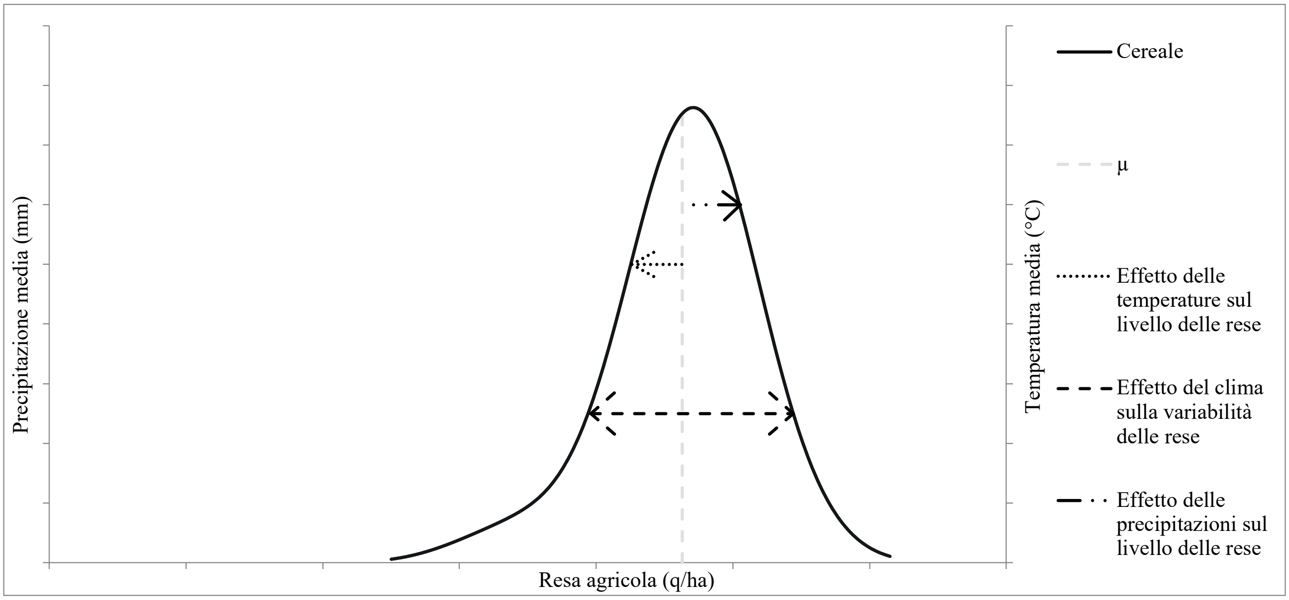
I dati sulla resa agricola riguardano le principali colture cerealicole italiane (avena, frumento, mais, orzo, riso, segale) nell'arco temporale dal 1920 al 2015 ottenuti come serie storiche dal database dell'INEA[2], dell'ISTAT e del MIPAAF. Nel reperire i dati d'interesse, gli autori si sono assicurati che, nonostante le informazioni siano state attinte da tre banche dati differenti, i campioni siano omogenei.

La resa agricola è calcolata come rapporto della produzione totale rispetto la superficie totale, espressa in quintali su ettari (q/ha). Più precisamente si ottengono sei serie storiche, una per ogni coltura. Le serie storiche per antonomasia constano di diverse compo-

[1] L'errore di tipo I è il rifiuto dell'ipotesi nulla (H0) quando risulta vera; mentre l'errore di tipo II è l'accettazione di ipotesi nulla (H0) quando questa è falsa.

[2] INEA (Istituto Nazionale di Economia Agraria) 1924 al 1926, ISTAT (Istituto Nazionale di Statistica) dal 1927 al 2015 e MIPAAF (Ministero delle Politiche Agricole, Alimentari e Forestali) dal 1920 al 1923.

Fig. 1. Quadro concettuale.



Note: gli acronimi sono gradi Celsius (°C), millimetri (mm), quintali su ettari (q/ha).

nenti, quali la ciclicità[3], l'irregolarità, la stagionalità e la tendenza a lungo termine (Turvey, Zhao, 1999; Ker, Goodwin, 2000; Hennessy, 2009). Tali componenti possono essere relazionate in maniera moltiplicativa (Popp *et al.*, 2005; Ye *et al.*, 2015; Lu *et al.*, 2017). Un modello moltiplicativo è appropriato quando l'ampiezza dell'oscillazione stagionale aumenta (o diminuisce) proporzionalmente all'aumento (o diminuzione) del livello della serie. Le serie storiche sono state detrendizzate[4] per la caratterizzazione del fenomeno in osservazione e per la previsione di valori futuri, al netto dell'innovazione tecnologica (Leng, Huang, 2017; Lu *et al.*, 2017; Setiyono *et al.*, 2018).

$$\varepsilon_t = \frac{y_t}{y_t^T} \tag{1}$$

ε_t rappresenta i residui della serie al netto del trend, y_t è il valore della resa tal quale, mentre y_t^T la tendenza a lungo termine.

In seguito alla detrendizzazione delle rese storiche si ottengono degli indici adimensionali di serie storiche. Risulta necessario normalizzare tali indici rapportandoli ad un anno base, in questo caso il 2014[5].

$$y_t^{dT} = \varepsilon_t * y_{2014} \tag{2}$$

y_t^{dT} la serie detrendizzate ed y_{2014} il valore della resa nel 2014.

La detrendizzazione dei dati è valutata dagli autori come una scelta metodologica efficace agli obiettivi dell'elaborato, senza implicare delle limitazioni allo svolgimento dell'analisi.

Le distribuzioni[6] delle rese agricole sono state ottenute tramite un metodo non parametrico: *kernel density estimation* (Turvey, Zhao, 1999; Popp *et al.*, 2005; Ye *et al.*, 2015). Considerando un campione di dati, in questo caso le osservazioni delle serie, una variabile casuale, la resa e avvalendosi di una costante del kernel e di una bandwidth è possibile analizzare le distribuzioni delle rese. Variando attentamente il parametro h[7] è possibile

[3] La ciclicità è originata da condizioni di espansione o contrazione del contesto economico; l'irregolarità è data da movimenti erratici o accidentali provocati da una serie di circostanze, di entità trascurabile. La stagionalità rappresenta le oscillazioni originate da fattori climatici (alternanza delle stagioni) e di organizzazione sociale; il trend è il movimento tendenziale monotono di fondo, di lungo periodo.

[4] La detrendizzazione consta nell'ottenere la linea di tendenza per ogni serie, quindi calcolare il valore tendenza, per ogni anno. Infine, dividere il valore originario della serie per il valore tendenza calcolato e moltiplicarlo per un anno base della serie.

[5] Seguendo il criterio di selezione dell'anno che fosse comune per tutte le serie storiche e più recente possibile dell'arco temporale considerato.

[6] Sono stati rimossi gli outlier (calcolando il limite inferiore Q1-(IQR*1,5) e quello superiore Q3+(IQR*1,5). Le osservazioni inferiori al limite inferiore e quelle superiori al limite superiore sono state scartate. Queste sono state reintrodotti (insieme ai valori di resa mancanti in origine) tramite un'interpolazione lineare (utilizzando i dati più prossimi a quelli mancanti).

[7] Troppo piccolo la distribuzione risulta appuntita, troppo grande risulta smussata.

Tab. 1. Rassegna della letteratura.

Studio		Oggetto d'analisi					Risultati			
Autore	Anno pubblicazione	Coltura		Territorio		Periodo considerato	Livello rese		Variabilità rese	
		Cereali*	Altro	PS	PVS		T	P	T	P
Black and Thompson	1978	x	Fagioli	x		1870-1970	-			
Furuya and Koyama	2005	x	Soia	x	x	1961-2000	-	+		
Schlenker and Roberts	2006	x		x		1950-2004	-			
Thornton *et al.*	2009	x	Fagioli		x	2000-2050	-	+		
Cabas *et al.*	2010	x	Soia	x		1981-2006	-	+		
Finger	2010	x		x		1961-2006			+	+
Lobell and Burke	2010	x			x	2010-2050	-	+		
Peltonen-Sainio *et al.*	2010	x	Barbabietola, colza, patata	x		1975-2008	-	+		
Rowhani *et al.*	2011	x			x	1992-2005	-	+		
Sarker *et al.*	2012	x			x	1972-2009	-	+		
Barnwal and Kotani	2013	x			x	1971-2004	-	+		
Briche *et al.*	2014		Vite	x		1971-2000			+	+
Challinor *et al.*	2014	x		x		2010-2100	-	+	+	
Gaudin *et al.*	2015	x	Soia	x		1982-2012	-	+		
Ray *et al.*	2015	x	Soia	x	x	1979-2008			+	+
Trnka *et al.*	2016	x		x		1901-2012	-			
Kim and Moschini	2018	x	Soia	x		1971-2015	-	+		
Agnolucci and De Lipsis	2019	x		x		1960-2020	-			
Fletcher *et al.*	2020	x		x		1900-2016	-	+		
Diffenbaugh *et al.*	2021	x		x		1991-2017	-	+		

Note: * avena, frumento, mais, orzo, riso, sorgo; gli acronimi sono Paesi sviluppati (PS), Paesi in via di sviluppo (PVS), temperature (T) e precipitazioni (P); la simbologia utilizzata rappresenta rispettivamente un decremento (-) oppure un incremento (+) delle variabili in esamina.

mettere in luce i pattern significativi, tralasciando quelli non significativi. Sono stati redatti i grafici di stima del kernel (riportati in appendice), uno per ogni serie storica, per osservare la densità di probabilità di ciascuna coltura in esamina. La normalità delle distribuzioni è stata verificata analiticamente con due test statistici[8] (Shapiro-Wilk Test e d'Agostino-Pearson) ed attraverso i qq-plot[9] (riportati in appendice) tale ipotesi è stata confermata graficamente (Hennessy, 2009; Lu *et al.*, 2017; Setiyono *et al.*, 2018). È stato individuato un andamento normale nella distribuzione dell'avena e in quella della segale.

La Tabella 2 fornisce le statistiche descrittive per le rese delle coltivazioni analizzate. La media storica dell'avena è pari a 23,2 q/ha, quella della segale 28,3 q/ha, quella dell'orzo 36,3 q/ha, quella del frumento 38,5 q/ha, quella del riso si attesta a 64 q/ha, nettamente superiore è la media storica del mais con 102,4 q/ha. Il grafico in Figura 2 riporta le distribuzioni dei cereali analizzati evidenziando tutti andamenti gaussiani, in seguito alla normalizzazione.

2.2 Fattori climatici

Quando si definisce il clima si fa riferimento ad una determinata area geografica, per la quale vengono definite le condizioni medie dell'atmosfera, in seguito ad osservazioni di almeno trent'anni consecutivi (World Meteorological Organization).

In questo studio sono state prese in considerazione le temperature e le precipitazioni medie annuali per il territorio italiano a livello nazionale, nell'arco temporale dal 1920 al 2015. I dati d'interesse sono stati estratti dalla fonte Climate Change Knowledge Portal Word Bank.

[8] In entrambi ho le seguenti caratteristiche: H0 (la distribuzione dei dati è normale), H1 (la distribuzione dei dati non è normale), α è il livello di significatività (probabilità di accettare o rifiutare l'ipotesi nulla), fissato pari a 0,05, infine p-value è il valore di probabilità (probabilità che la differenza tra i valori osservati e quelli calcolati sia significativa o casuale). P-value > alpha accettazione di H0, p-value ≤ alpha accettazione H1.

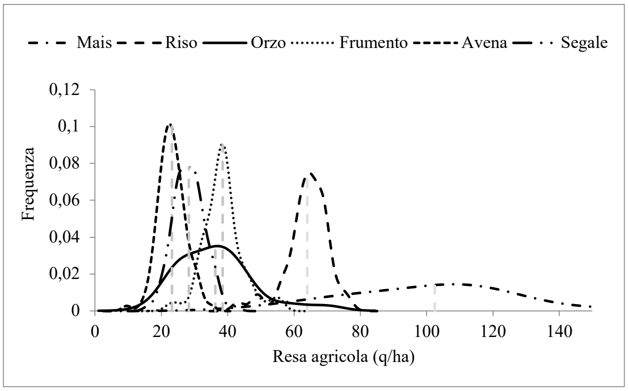
[9] Frappongono i quantili della distribuzione calcolata cumulata con quelli di una distribuzione normale cumulata.

Tab. 2. Statistiche descrittive.

	μ	σ	Q1	Q3
Colture (q/ha)				
Avena	23,2	4,1	20,5	25,5
Frumento*	38,5	5,9	35,4	40,3
Mais	102,4	27,6	82,0	115,7
Orzo	36,3	11,1	27,2	41,7
Riso	64,0	6,4	61,7	68,2
Segale	28,3	4,6	25,1	31,2
Variabili climatiche				
Precipitazioni (mm)	70,7	6,4	66,0	74,9
Temperature (°C)	11,8	0,4	11,5	12,1

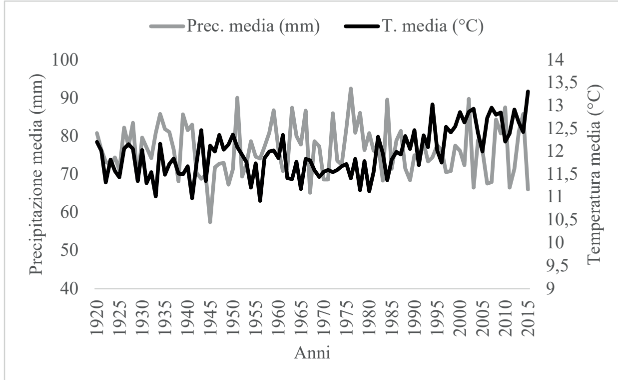
Note: gli acronimi sono media (μ), deviazione standard (σ), primo quartile (Q1), terzo quartile (Q3), quintali/ettari (q/ha), gradi Celsius (°C), millimetri (mm).
* sia la varietà duro che tenero.
Fonte: elaborazione su dati CCKP (per i fattori climatici), INEA, ISTAT, MIPAAF (per le rese agricole).

Fig. 2. Distribuzione delle rese agricole.



Note: l'acronimo è quintali su ettari (q/ha).
Fonte: elaborazione su dati INEA, ISTAT, MIPAAF.

Fig. 3. Distribuzione delle variabili climatiche.



Note: gli acronimi sono gradi Celsius (°C) e millimetri (mm).
Fonte: elaborazione su dati CCKP.

Dal 1920 in poi la temperatura aumenta di almeno mezzo grado centigrado, raggiungendo un "picco" verso la fine degli anni '40 (Fig. 3). Segue una breve discesa termica, poi, a partire dal 1980, una netta risalita, nel corso della quale la temperatura guadagna 1°C in soli due decenni, per stabilizzarsi sui nuovi valori raggiunti nel corso degli anni Duemila. La piovosità annuale mostra un ciclico alternarsi di periodi piovosi e periodi di siccità. L'andamento delle piogge segnala una lenta diminuzione, oscillando attorno alla media. Si segnala un periodo di forte siccità negli anni Quaranta, un trentennio abbastanza piovoso tra il 1950 ed il 1980, ed un calo delle piogge tra il 1995 fino ad oggi. Il risultato è un'Italia decisamente più calda, rispetto ad una volta, mentre le precipitazioni hanno subito, almeno per il momento, solo una lieve diminuzione (Ray *et al.*, 2015; Trnka *et al.*, 2016; Agnolucci, De Lipsis, 2019). Sia per le temperature che per le precipitazioni si parla di una media generale, riguardante tutto il territorio nazionale. Le serie climatiche (così come le serie agricole), sono state detrendizzate e normalizzate, considerando come anno base[10] l'osservazione del 1996 per le temperature e del 1997 per le precipitazioni.

Le due distribuzioni[11] sono state studiate tramite il metodo non parametrico di stima del kernel, grazie al quale le due variabili climatiche sono state rappresentate graficamente (grafici riportati in appendice). La normalità delle distribuzioni è stata verificata analiticamente con due test statistici (Shapiro-Wilk Test e d'Agostino-Pearson) ed attraverso i qq-plot (riportati in appendice) tale ipotesi è stata confermata graficamente. È stato individuato un andamento normale in entrambe le distribuzioni (Schlenker, Roberts, 2006; Rowhani *et al.*, 2011; Diffenbaugh *et al.*, 2021). La Tabella 2 fornisce le statistiche descrittive per le due variabili climatiche analizzate. La media storica delle temperature è pari a 11,8 °C, quella delle precipitazioni 70,7 mm.

2.3 Modelli econometrici

Il quadro econometrico che adottiamo è la classe generale di modelli non lineari, spesso impiegati come

[10] Per le temperature è stata scelta l'ultima osservazione disponibile prima dell'inizio della fase di netta crescita (1996). Per le precipitazioni è stata selezionata l'osservazione dell'anno successivo (1997), poiché il dato del 1996 è un *outlier*.
[11] Sono stati rimossi gli *outlier* e reintrodotti (insieme ai valori di temperatura e precipitazione mancanti in origine) tramite la funzione di interpolazione lineare.

dispositivi di previsione in economia agraria, nelle scienze climatiche per rappresentare l'andamento delle temperature, delle precipitazioni e dei loro rispettivi impatti (Thornton *et al.*, 2009; Trnka *et al.*, 2016; Agnolucci, De Lipsis, 2019). Questo approccio ci permette di eseguire uno studio esplicito e generale delle rese agricole, catturando il ruolo potenziale delle variabili climatiche, le cui conseguenze possono variare nel tempo.

Eseguiamo la nostra analisi empirica in due fasi distinte, ognuna ideata per affrontare una diversa domanda di ricerca. Nella prima fase, indaghiamo se la resa agricola è influenzata da variabili meteorologiche e forniamo una misura quantitativa dei loro effetti. Nella seconda fase, esaminiamo la variabilità delle rese, esploriamo la potenziale esistenza di correlazione con i trend climatici. Di seguito, descriviamo più in dettaglio ciascuna delle due fasi dello studio.

L'obiettivo principale di questo studio è l'impiego di un approccio di regressione multipla per analizzare l'effetto della variazione storica delle temperature e delle precipitazioni nelle distribuzioni delle principali colture cerealicole in Italia. È stata postulata una semplice equazione di regressione non lineare per valutare le riposte delle rese agricole ai cambiamenti climatici. Nello specifico, in linea con Kim, Moschini (2018) e Tappi *et al.* (2022), la resa: y_{kt} per la coltura k al tempo t è modellata come:

$$y_{kt} = \alpha_1 + \beta_1 T_t + \delta_1 T_t^2 + \gamma_1 P_t + \theta_1 P_t^2 + \varepsilon_{kt} \quad (3)$$

α_1 è la costante, T_t è il trend lineare delle temperature, P_t è il trend lineare delle precipitazioni, $T^2{}_t$ è il trend al quadrato delle temperature, $P^2{}_t$ è il trend al quadrato delle precipitazioni, ε_{kt} è l'errore.

Seguendo la letteratura (e.g. Finger, 2010; Rowhani *et al.*, 2011; Barnwal and Kotani, 2013), una seconda equazione di regressione non lineare è stata postulata per valutare la variabilità delle rese agricole, in risposta ai cambiamenti climatici. In dettaglio, la deviazione standard bootstrap[12] della resa $\sigma(y_{kt})$ per la coltura k al tempo t è modellata come:

$$\sigma(y_{kt}) = \alpha_1 + \beta_1 \sigma(T_t) + \delta_1 \sigma(T_t^2) + \gamma_1 \sigma(P_t) + \theta_1 \sigma(P_t^2) + \varepsilon_{kt} \quad (4)$$

α_1 è la costante, T_t è la deviazione standard del trend lineare delle temperature P_t è la deviazione standard del trend lineare delle precipitazioni, $T^2{}_t$ è la deviazione standard del trend al quadrato delle temperature, $P^2{}_t$ è la deviazione standard del trend al quadrato delle precipitazioni, ε_{kt} è l'errore. Usando il modello (4) si assume che le differenti variabilità nelle temperature e nelle precipitazioni possano avere un effetto sulla produttività dei cereali considerati.

Il nostro metodo consiste essenzialmente nell'utilizzare tre specifiche econometriche delle due equazioni descritte. In un primo caso sono stati considerati gli effetti complessivi del clima su tutte le colture in esamina, ipotizzando una relazione non lineare tra le rese cerealicole e le temperature, parimenti tra rese e precipitazioni. Nella seconda specifica sono stati implementati gli effetti fissi dei fattori climatici su ciascuna coltura. Infine, nel terzo sono state inserite delle variabili fittizie (variabili che rappresentano gli effetti della temperatura e delle precipitazioni specifiche della coltura) per ogni coltivazione, linearmente alle temperature e alle precipitazioni.

3. RISULTATI E DISCUSSIONE

In questa sezione, illustriamo i risultati che otteniamo dall'applicazione della metodologia sopra descritta sui dati italiani. L'obiettivo di questa fase è comprendere la natura delle variazioni quantitative delle rese dei cereali selezionati, considerando l'influenza dei fattori meteorologici (Rowhani *et al.*, 2011; Agnolucci, De Lipsis, 2019; Diffenbaugh *et al.*, 2021). Valutiamo l'impatto delle condizioni climatiche sul tasso di crescita a lungo termine delle rese agricole. Seguendo le indicazioni presenti in letteratura (Schlenker, Roberts, 2006; Lobell, Burke, 2010; Trnka *et al.*, 2016), la ricerca ha preso in considerazione due approcci econometrici (descritti nella sezione *2.3*): stimare gli effetti del clima sul livello e sulla variabilità delle rese.

I risultati dell'applicazione della nostra metodologia sono mostrati nella Tabella 3. Osservando i risultati si può affermare che le relazioni tra l'andamento del clima e quello delle rese cerealicole sono coerenti con quanto riscontrato dalla letteratura scientifica (Furuya, Koyama, 2005; Finger, 2010; Sarker *et al.*, 2012; Trnka *et al.*, 2016).

Nello specifico per le temperature non si individua un effetto generalizzato per i sei cereali analizzati, mentre per le colture del mais e dell'orzo l'aumento delle temperature comporta una riduzione delle rese; tale riscontro ha andamento non lineare (Schlenker, Roberts, 2006; Lobell, Burke, 2010). Per le precipitazioni si riscontra una correlazione positiva e non lineare con le rese cerealicole; quindi, la contrazione di queste causa una riduzione delle rese, in maniera più accentuata per il mais (Rowhani *et al.*, 2011; Agnolucci, De Lipsis, 2019).

In merito all'analisi dell'impatto del clima sulla variabilità delle rese agricole risulta che la deviazione

[12] Tecnica statistica di ricampionamento con re-immissione per approssimare la distribuzione campionaria di una statistica.

Tab. 3. Stime sul livello e sulla variabilità delle rese.

Variabili climatiche	Livello rese (1)			Variabilità rese (2)		
	I	II	III	I	II	III
T	7.605 (5.127)	-43.87 (71.91)	-37.33 (70.12)	0.326*** (0.0367)	1.074** (0.514)	0.937** (0.419)
$(T)^2$	0.153** (0.0625)	0.188** (0.0795)	0.188** (0.0773)	-0.00196*** (0.000448)	-0.00247*** (0.000568)	-0.00247*** (0.000462)
P	102.9*** (20.85)	103.8*** (20.90)	102.4*** (20.51)	0.392*** (0.149)	0.378** (0.149)	0.358*** (0.122)
$(P)^2$	-0.0487*** (0.0102)	-0.0492*** (0.0103)	-0.0492*** (0.00998)	-0.000183** (7.32e-05)	-0.000176** (7.33e-05)	-0.000176*** (5.96e-05)
T* *Dummy* (coltura)						
Avena			1.055 (7.342)			0.00202 (0.0438)
Frumento			-1.768 (7.342)			0.0442 (0.0438)
Mais			-28.50*** (7.342)			0.597*** (0.0438)
Orzo			-13.04* (7.342)			0.201*** (0.0438)
Riso			3.041 (7.342)			-0.0239 (0.0438)
P* *Dummy* (coltura)						
Avena			-0.303 (4.133)			0.0148 (0.0247)
Frumento			-0.424 (4.133)			0.0191 (0.0247)
Mais			9.689** (4.133)			0.0709*** (0.0247)
Orzo			0.415 (4.133)			0.0158 (0.0247)
Riso			-0.974 (4.133)			-0.00344 (0.0247)
Anni		0.524 (0.730)	0.524 (0.710)		-0.00762 (0.00522)	-0.00762* (0.00424)
Effetti fissi sulle colture	No	Si	Si	No	Si	Si
Costante	-282.0*** (63.68)	-1,337 (1,434)	-1,329 (1,395)	10.43** (4.704)	18.13* (10.25)	18.19** (8.328)
Osservazioni	576	576	576	576	576	576

Note: gli acronimi sono temperature (T), precipitazioni (P); (1) rese *detrendizzate*, (2) deviazione standard bootstrap delle rese *detrendizzate*; in parentesi sono riportati gli errori standard ***p<0.01, **p<0.05, *p<0.1.
Fonte: elaborazione su dati CCKP, INEA, ISTAT, MIPAAF.

standard delle rese ha una correlazione positiva con il trend delle temperature a livello generico (maggiormente per mais e orzo) e che tale relazione non è lineare (Barnwal, Kotani, 2013; Diffenbaugh *et al.*, 2021).

Quindi si evince che l'aumento delle temperature comporti un aumento della variabilità delle rese. Invece, riguardo le precipitazioni, la loro diminuzione implica una maggiore variabilità delle rese agricole in maniera generalizzata, più accentuata per il mais (Ray *et al.*, 2015; Trnka *et al.*, 2016). In conclusione, si può asserire che il trend[13] delle temperature e quello delle precipitazioni influenzano notevolmente sia il livello medio delle rese sia la loro variabilità, in maniera eterogenea fra le colture, in particolare appare evidente l'impatto sul mais, le

[13] Ottenuta come differenza tra le serie storiche delle temperature e precipitazioni tal quali e le serie storiche detrendizzate e normalizzate delle suddette.

cui rese hanno maggiormente risentito dei cambiamenti climatici in corso. In questo modo abbiamo quantificato le effettive perdite che hanno interessato il comparto cerealicolo italiano, in seguito al cambiamento del clima. Delineare delle stime permette di comprendere quali siano le difficoltà a cui l'agricoltura va incontro, così da intraprendere le opportune modifiche nella gestione del sistema agricolo.

Quest'area di ricerca, attiva da diversi decenni, presenta molti sviluppi recenti, al fine di individuare il modo migliore di misurazione dei danni climatici nel comparto agro-alimentare (Thornton *et al.*, 2009; Barnwal, Kotani, 2013; Gaudin *et al.*, 2015). L'instabilità e la vulnerabilità delle rese cerealicole osservate in questo studio potranno aggravarsi negli anni futuri. La tendenza, delineata nell'elaborato e prevista dalla letteratura corrente, di un clima più caldo e secco può accentuare la riduzione dei raccolti (Furuya, Koyama, 2005; Finger, 2010; Sarker *et al.*, 2012; Trnka *et al.*, 2016; Lamonaca *et al.*, 2021). Ampliare le conoscenze scientifiche, per stimare le conseguenze economiche dei cambiamenti climatici è importante sia come area di indagine accademica, che come input nella formazione di decisioni politiche di adattamento e mitigazione (Briche *et al.*, 2014; Challinor *et al.*, 2014; Ray *et al.*, 2015).

I dati panel, come quelli utilizzati nel seguente studio, contengono molte informazioni sugli effetti delle variazioni meteorologiche a breve, medio e lungo termine. La divulgazione di tali informazioni può contribuire alla realizzazione un approccio innovativo per aiutare a adattare gli agroecosistemi ai prossimi cambiamenti nelle condizioni di coltivazione delle colture; affrontando allo stesso tempo le questioni di sostenibilità associate al mantenimento delle rese in ambienti di produzione sempre più difficili. Questo complesso problema richiede l'adozione di politiche coerenti ed integrate per affrontare i temi del cambiamento climatico.

4. CONSIDERAZIONE CONCLUSIVE

I cambiamenti climatici sono sempre più evidenti in termini economici e preoccupano l'intera società. Gli effetti non saranno semplici, tantomeno equi: alcuni settori produttivi saranno molto più interessati di altri a causa del diverso grado di vulnerabilità agli eventi meteo-climatici. Il settore agroalimentare è un caso emblematico: gli effetti dei cambiamenti climatici saranno evidenti sia dal lato produttivo, sia da quello dei consumatori, le cui abitudini alimentari sono destinate a modificarsi. Le colture di pieno campo (e.g. cereali) sono, più di altre, esposte agli eventi meteorologici.

Il presente studio mostra come le tendenze meteo-climatiche giochino un ruolo fondamentale nella determinazione degli andamenti delle rese agricole delle colture cerealicole in Italia. Seppure il fenomeno sia stato già studiato (Thornton *et al.*, 2009; Barnwal, Kotani, 2013; Gaudin *et al.*, 2015), il presente studio ha il pregio di concentrare l'attenzione sul caso italiano e sulle rese dei principali cereali coltivati in Italia (soprattutto mais e orzo): gli effetti sulle rese appaiono complessi e altamente non lineari. In dettaglio, si riscontra che le temperature e le precipitazioni influenzano notevolmente sia il livello medio delle rese che la loro variabilità. Tuttavia, tali effetti sono eterogenei fra le colture poste in rassegna, con particolari evidenze sull'impatto per il mais, le cui rese hanno maggiormente risentito dei cambiamenti climatici in corso.

Il nostro contributo aiuta a stimolare il dibattito sulle strategie da porre in essere per limitare gli effetti negativi dei cambiamenti climatici e coglierne le opportunità, orientando la ricerca futura e la progettazione di strumenti di gestione del rischio legati agli andamenti meteorologici. La ricerca in questo ambito è certamente promettente, soprattutto alla luce della incombente necessità di attenuare il cambiamento climatico (Santeramo 2019; Kolstad, Moore, 2020; Tappi *et al.*, 2022).

La crescente frequenza delle avversità climatiche impone la ricerca di nuove soluzioni in ambito assicurativo. A tal proposito, l'istituzione del Fondo di mutualità nazionale (Fondo MeteoCAT) è una soluzione strategica per la gestione degli eventi catastrofali, in linea con le linee programmatiche europee di lungo periodo (Cordier, Santeramo, 2020).

Quantificare gli effetti dell'andamento delle temperature e delle precipitazioni sui dati agricoli è importante anche per pianificare schemi assicurativi basati su indici meteo (Kahil, Albiac, 2013; Trnka *et al.*, 2016; Agnolucci, De Lipsis, 2019). Negli ultimi anni, l'attenzione nei confronti delle assicurazioni basate sugli indici meteorologici (*Weather Index-Based Insurances*, WIBI) è cresciuta notevolmente, soprattutto perché esse possono aiutare gli agricoltori a far fronte ai rischi climatici superando i problemi più comuni di assicurazioni tradizionali basate sull'indennizzo, ovvero l'informazione asimmetrica, gli alti costi di transazione, il rischio morale e la selezione avversa (Santeramo, Di Gioia, 2018). Inoltre, le WIBI non possono essere manipolate né dagli assicuratori né dagli assicurati, perché sono indici raccolti da dataset storici e aggiornati da enti riconosciuti (Kolstad, Moore, 2020; Tappi *et al.*, 2022).

La gestione del rischio in agricoltura diverrà sempre più un pilastro della politica agricola. Si prevede che le fluttuazioni della temperatura e delle precipitazioni aumenteranno con il cambiamento climatico globale, con eventi estremi più frequenti e più intensi. Gli scenari climatici futuri prevedono una potenziale contrazione complessiva delle rese agricole (Furuya, Koyama, 2005; Finger, 2010; Sarker *et al.*, 2012; Cooper, DelBeCq, 2014; Trnka *et al.*, 2016; Santeramo, Russo, 2021), quindi se non si interviene potenziando gli strumenti tecnici disponibili gli effetti sull'intero sistema agroalimentare saranno catastrofici.

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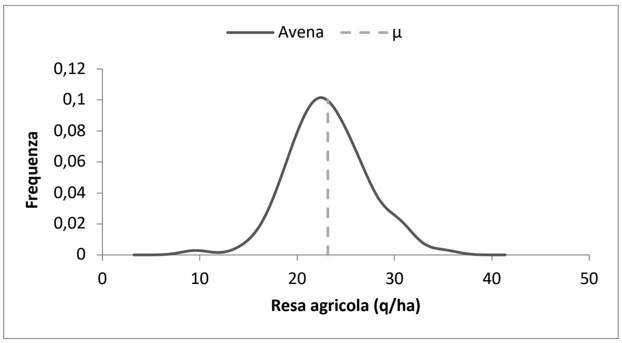
APPENDICE

a. Andamento delle rese agricole

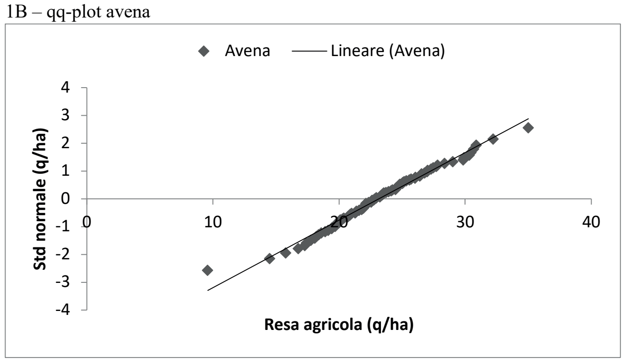
Al fine di rendere esauriente la comprensione del fenomeno agricolo, l'analisi è stata accompagnata dal supporto di alcuni grafici. Per descrivere l'andamento delle distribuzioni delle rese agricole sono stati utilizzati i kdc (*kernel density charts*), i quali rappresentano la funzione di densità di probabilità (*probability density function*), tramite un metodo non parametrico: *kernel density estimation*. Per osservare la densità di probabilità delle distribuzioni delle colture, sono stati redatti sei grafici, uno per ogni coltivazione considerata. Si riportano in ascissa i valori della resa agricola espressi in quintali su ettari (q/ha) e in ordinata i valori della frequenza dei dati. Solamente per due coltivazioni, quali avena e segale, l'andamento riscontrato è normale. In aggiunta a questa tipologia di grafici sono stati eseguiti dei qq-plot (*quantile-quantile plot*). Questi frappongono i quantili della distribuzione calcolata cumulata con quelli di una distribuzione normale cumulata. Tanto più i quantili delle due sono uguali, tanto più i dati confermano l'ipotesi gaussiana. È un metodo di rapida applicazione e di immediata inter-

Fig. A.1. Rese agricole.

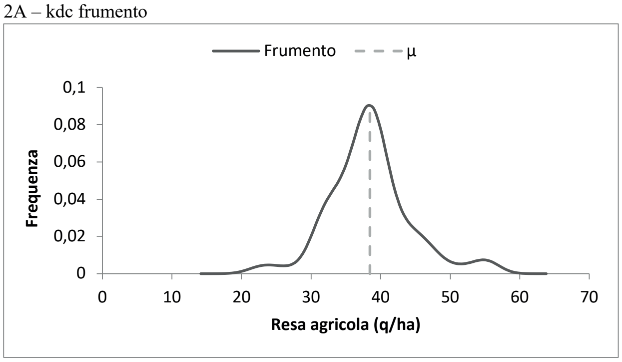
1A – kdc avena



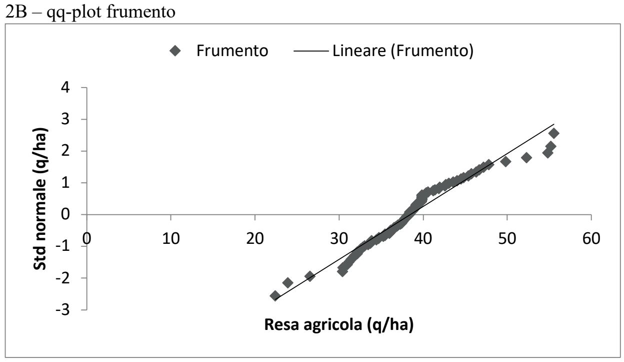
1B – qq-plot avena



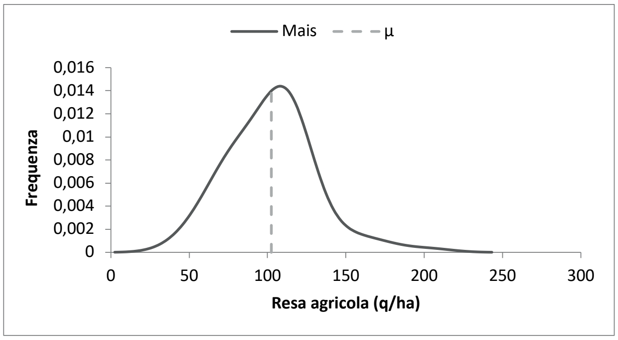
2A – kdc frumento



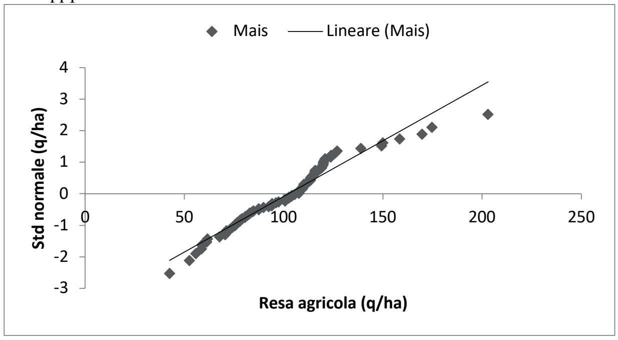
2B – qq-plot frumento



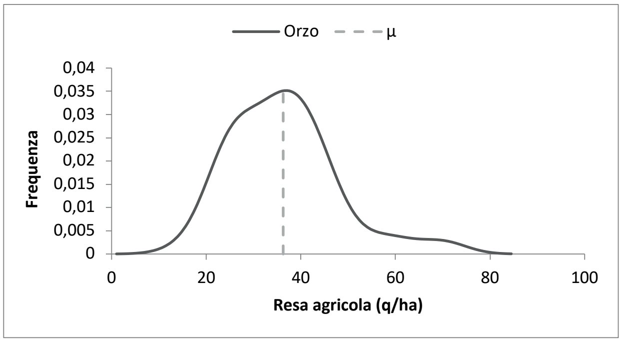
3A – kdc mais



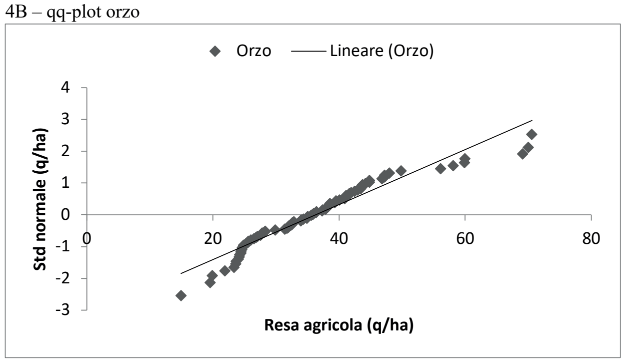
3B – qq-plot mais



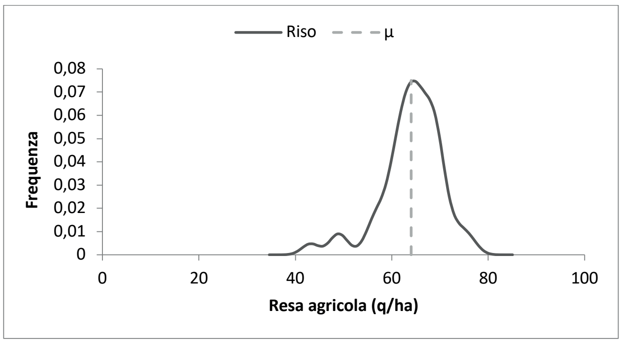
4A – kdc orzo



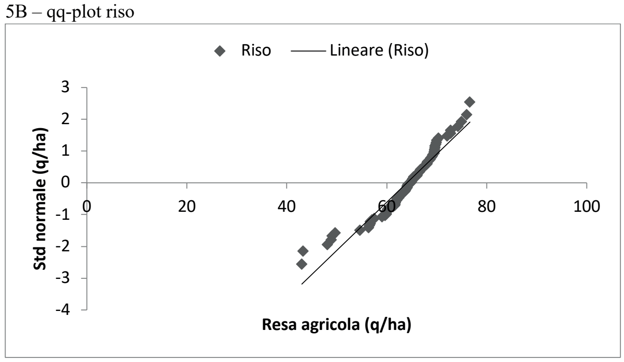
4B – qq-plot orzo



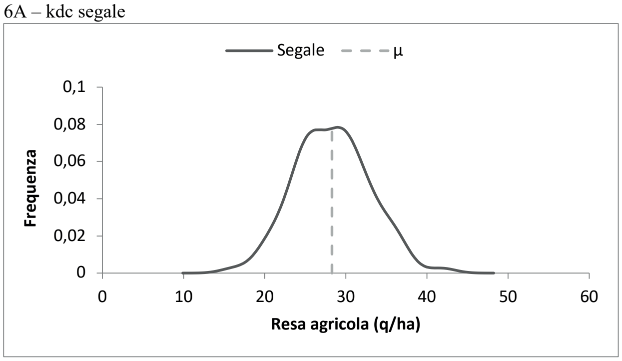
5A – kdc riso



5B – qq-plot riso



6A – kdc segale



6B – qq-plot segale

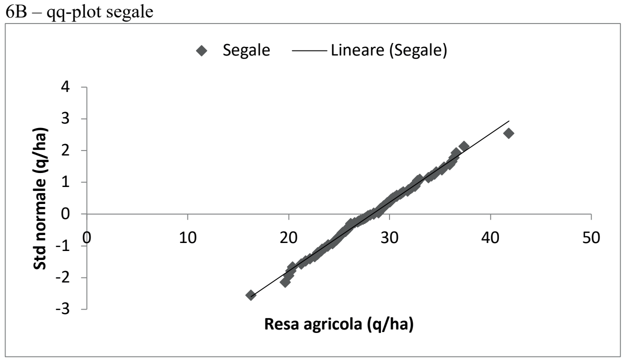
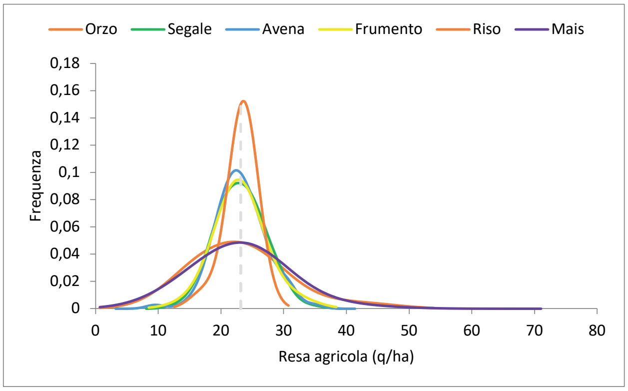


Fig. A.2. Variabilità delle rese agricole.



Note: le medie sono centrate al valore della media minore delle sette, dell'avena; l'acronimo è quintali su ettari (q/ha).
Fonte: elaborazione su dati INEA, ISTAT, MIPAAF.

pretazione. Sono riportati sei grafici, uno per ogni coltivazione considerata. In ascissa sono indicati i valori della resa agricola osservati, espressi in quintali su ettari (q/ha) ed in ordinata i valori della resa agricola teorici, espressi parimenti in quintali su ettari (q/ha). Solamente per due colture, quali avena e segale, l'ipotesi gaussiana è confermata.

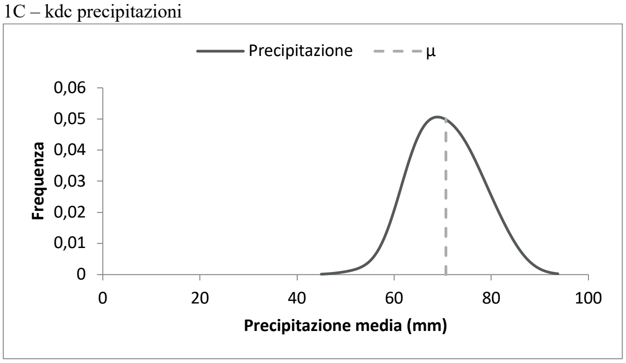
In aggiunta ai grafici esaminati ne è stato redatto un ulteriore, nel quale si osservano contemporaneamente le rese analizzate di tutte le colture. Per tali rese la distribuzione è stata rapportata alla coltura con minore valore medio di resa negli anni, l'avena. Così facendo le distribuzioni delle diverse coltivazioni hanno subito una traslazione verso i valori della coltura di riferimento, mentre le medie, per ovvi motivi, sono coincidenti con quella dell'avena.

b. Andamento delle variabili climatiche

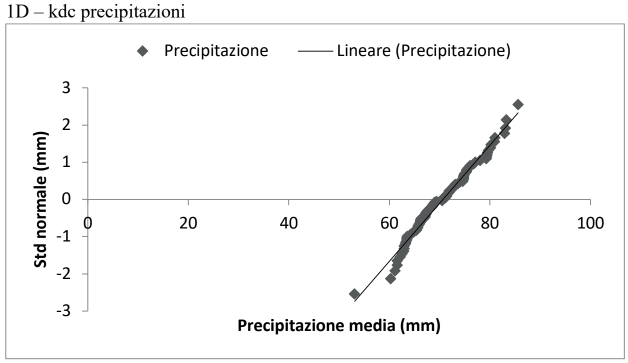
Per i due fattori climatici presi in considerazione, quali temperature e precipitazioni, l'analisi è stata supportata da alcuni grafici. Parimenti a quanto eseguito per le rese agricole, al fine di rendere i fenomeni climatici meglio comprensibili, sono state redatte due tipologie di grafici. Sono riportati di seguito i kdc (kernel density charts), con i quali mediante un metodo non parametrico, viene descritta la funzione di densità di probabilità per le temperature e le precipitazioni. In ascissa sono riportate rispettivamente, le temperature medie espresse in gradi Celsius (°C) e le precipitazioni medie in millimetri (mm), mentre in ordinata la frequenza dei dati.

Fig. A.3. Fattori climatici.

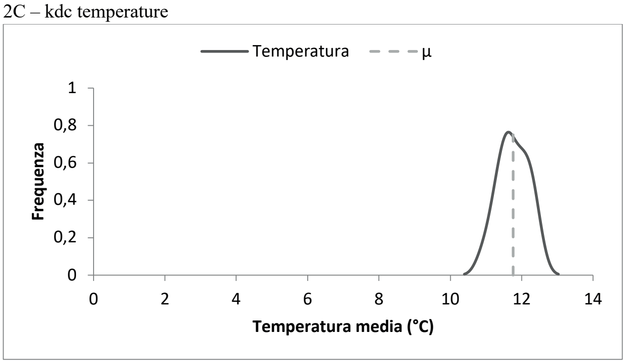
1C – kdc precipitazioni



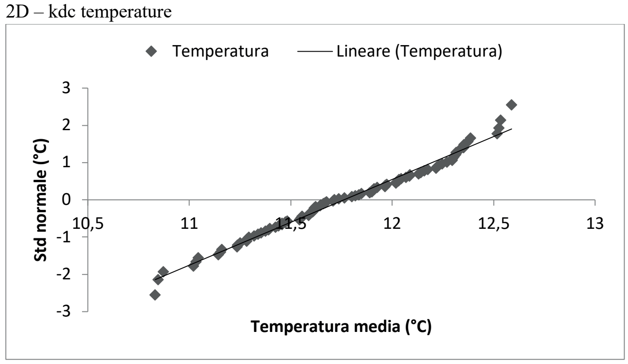
1D – kdc precipitazioni



2C – kdc temperature



2D – kdc temperature



Per entrambi i fattori climatici le distribuzioni presentano andamento normale. Tale normalità è stata inoltre verificata con un'altra tipologia di grafici, i qq-plot (quantile-quantile plot). Per i due fattori climatici, in ascissa sono riportati i valori delle precipitazioni medie o delle temperature medie osservate, espressi rispettivamente in millimetri (mm) ed in gradi Celsius (°C), in ordinata i valori di precipitazioni o di temperature teorici, espressi allo stesso modo in millimetri (mm) ed in gradi Celsius (°C). Per entrambe le variabili climatiche l'ipotesi di normalità è confermata.

c. Andamento della superficie agricola utilizzata nazionale

È interessante osservare come nel corso degli anni analizzati la superficie destinata al comparto agricolo sia cambiata. Come si evince dalla Tabella A.1., complessivamente dal secondo dopoguerra la superficie adibita all'agricoltura è progressivamente diminuita. Nello specifico si evidenzia un decremento di qualche punto percentuale tra gli anni 1930-1961-1970, dopo di che tra gli anni '70 ed '80 si assiste ad una contrazione di circa il 30%. Da questo momento in poi la SAU (superficie agricola utilizzata) continuerà a presentare una discesa lenta e graduale.

Tab. A.1. Variabilità della superficie agricola utilizzata.

Anni	SAU (Mha)
1930	25,6
1961	25,8
1970	24,4
1980	15,4
1987	15,1
1993	14,7
2000	13,2
2010	12,9
2013	12,4
2016	12,6

Note: gli acronimi sono superficie agricola utilizzata (SAU) e milioni di ettari (Mha).
Fonte: elaborazione su dati ISTAT.

Al fine di poter quantificare nello specifico, la variabilità della superficie agricola utilizzata, per le colture e l'arco temporale d'interesse, è stato formulato un indice di stabilità (IS) adimensionale:

$$IS = \frac{\sqrt{\sum(s - s_i)}}{\sqrt{[max/s - s_i/^2] * n}}$$

s rappresenta la superficie coltivata annualmente di una coltura, mentre s_i è il valore di superficie messa a coltura di riferimento dell'anno 2014, infine n è il numero delle osservazioni di superficie disponibili nell'arco temporale scelto (1920-2015). Tale indice può essere al massimo pari a 1, in caso di elevata costanza della superficie messa a coltura o viceversa pari a 0, in caso di notevole variabilità della stessa. I risultati, nella Tabella A.2., evidenziano come per le coltivazioni dell'avena, del frumento e della segale l'andamento della superficie è piuttosto omogeneo, mentre per le rimanenti colture l'indice manifesta una contenuta variabilità della superficie.

Tab. A.2. Stabilità delle rese agricole nazionali.

Colture	IS
Avena	0,64
Frumento	0,63
Mais	0,38
Orzo	0,39
Riso	0,48
Segale	0,51

Note: l'acronimo è indice di stabilità (IS).
Fonte: elaborazione su dati ISTAT.

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Book Reviews

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The research presented in the book Kunneke *et al.* is part of a wider programme of inquiry that is investigating the multiple dimensions of interrelations between technology and institutions (Kunneke *et al.*, 2010; Ménard, 2014, 2017). Developing an articulated conceptualization of the relationships between technology and institutions and clarifying their role in infrastructure performance, the book represents a turning point in this research programme.

Network infrastructures are socio-technological systems characterized by strongly interdependent technological and institutional objects.

The basic theme of the book concerns the central idea that the performance of the network infrastructures depends upon the alignment between institutions and technology. This is innovative for two reasons: first, because it deepens the understanding of institutions with respect to socioeconomic life; second, because it makes clear that infrastructure services can be provided just by establishing a coherent linkage between technology and institutions, which are often addressed separately.

The analysis of network infrastructure performance is developed by moving from the awareness that *values* play a critical role in specifying which services are *essential* for a society. The Authors introduce an innovative conceptualization of network infrastructure, submitting that these services are guaranteed by the infrastructures' critical functions: *system control* (which pertains to the question of how the overall system – e.g., the flow between the various nodes and links – is being monitored and controlled and how the quality of service is safeguarded, associating technical requirements to effective institutional entities and consistent rules to allow them to perform adequately); *capacity management*, dealing with the allocation of scarce network capacity to certain users; *interconnection*, which refers to the coordination of activities and services between different segments that perform similar or complementary tasks in an infrastructure network; *interoperability*, referring to the requirements that components of infrastructure networks must satisfy in order to support the complementarity between different nodes and links that structure the network. The book argues that the issue of the technological coordination of complementary artefacts is not addressed in the economic literature. There is instead a need to specify the features of technology that are relevant for the safeguarding of critical functions (79-80).

Based on this starting point, the core of the proposed theoretical framework includes the articulation in three layers of technology (technological architecture, technological design, technological operations) and institutions (macroinstitutions, meso-institutions, microinstitutions).

The *technological architecture* articulates the constitutive technological features of a network infrastructure needed to provide generic services, the constitutive material components, and the technological arrangements of its mutually complementing parts required to provide generic services and safeguard the critical functions (p. 84). The *technological design* of a network infrastructure differs from its architecture: it denotes the contextual framing of the generic architecture in terms of particular services, specific material components, and the technological arrangements required to provide services (p.85). *Technical operations* refer instead to the configuration of technical devices, so that expected services are provided and critical functions are monitored and controlled given the context-specific design and architecture (p. 87)

Following Ménard (2014, 2017), the institutional framework is conceptualized in three layers. The macroinstitutions correspond to the institutional environment, as defined in North's theory (1990). The microinstitutions correspond instead to the governance structures (Williamson, 1985). The organizational layer is what the agents design and adopt to organize their transactions.

The concept of meso-institutions was introduced and elaborated by Ménard (2014, 2017) and posited at the core of an innovative research agenda. Meso-institutions are devices that are in charge of implementing the general rules of the game through their translation into rules specific to sectors and/or geographic areas, thus framing and delineating the domain of activities of actors (Mènard, 2014, p. 578). Meso-institutions are necessary because laws and norms are often abstract or ambiguous (Ménard, 2017). Thus, they need to be interpreted by devices that translate the general rules into specific guidelines and mechanisms that shape their implementation, adapting the definition and allocation of decision rights and their usage to the scope, space and time in which actors evolve (Ménard, 2017; Royer *et al.*, 2016; Rouviere, Royer, 2017; Soregaroli *et al.*, 2022).

More precisely, meso-institutions carry out three functions (Ménard, 2017): a) *Translation*: which consists of providing guidelines, information about norms, formations, and in broad terms makes the constitutional rules (North, 1990; Ostrom, 2009) context-specific (at the sector or geographic level) and, thus, manageable by actors operating at the microlevel; b) *Monitoring*: monitoring/controlling the implementation of rules to be translated, establishing procedures that actors have to follow and check their actual implementation;

c) *Enforcement and feedback*: based on the power to penalize those who do not comply with the rules and on the possibility of providing feedback to regulatory authorities (Ménard *et al.*, 2022).

The key result of the book is that the availability of network services – the *expected services* – depends upon *alignment between the technology and institutions.* The Authors clarify this as such: «Our understanding of alignment is more general and concerns the compatibility of coordination along the three layers of our framework: between the technological architecture and the macroinstitutions, between the technological design and the meso-institutions and between the operational technology and the microinstitutions» (p. 39). It is the ordered alignment of technology and institutions that guarantees the achievement of the expected services. The empirical parts of the book are very rich. While it offers wide confirmation of the theoretical proposal, it also makes available a set of finely conducted case studies that can guide the development of further sectoral studies.

The book makes a robust theoretical point in the research on the relationships between technology and institutions, basically because it substantiates the relationships in terms of alignment and coordination, thus qualifying the relationships themselves. This point opens many research possibilities, not only for institutional and new-institutional theorists but also for applied economics scholars and, in particular, for agricultural economists. Transition studies are actually demanding innovative contributions (Fresco *et al.*, 2021) in which the analytical capability of developing efficient models of transformative technologies has a central role. The changes in the socioecological systems triggered by the ecological transition strongly mobilized analytical attention on the dynamics of the network infrastructures. Moreover, logistics in food chains and standard management digitalization are just some fields of inquiry that could benefit from the theoretical framework built on by the book. For all these fields of inquiry, the book provides a conceptual toolbox for agricultural economists, one based on an innovative perspective and capable of opening new perspectives of research.

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