ISSN 2280-6180
www.fupress.net




BAE

VOL. 13, NO. 2, 2024

Bio-based and Applied Economics




FIRENZE UNIVERSITY PRESS

Bio-based and Applied Economics is the official journal of the Italian Association of Agricultural and Applied Economics – AIEAA (www.aieaa.org; E-mail: info@aieaa.org).

Journal Contacts:
Silvia Coderoni, Via Balzarini 1, Dipartimento di Bioscienze e Tecnologie Agro-Alimentari e Ambientali, 64100 Teramo; E-mail: scoderoni@unite.it
Fabio Bartolini, Via L. Borsari 46, Dipartimento di Scienze Chimiche, Farmaceutiche ed Agrarie, 44121 Ferrara; fabio.bartolini@unife.it

Available online at: http://www.fupress.com/bae

Università degli Studi di Firenze
Firenze University Press
via Cittadella, 7 - 50144 Firenze, Italy
www.fupress.com
E-mail: journals@fupress.com

ISSN 2280-6180 (print)
ISSN 2280-6172 (online)
Direttore Responsabile: Corrado Giacomini
Registrata al n. 5873 in data 10 maggio 2012
del Tribunale di Firenze

BAE

Bio-based and Applied Economics

Volume 13, Issue 2 - 2024

Firenze University Press

Bio-based and Applied Economics
Published by
Firenze University Press – University of Florence, Italy
Via Cittadella, 7 - 50144 Florence - Italy
http://www.fupress.com/bae

BAE
Bio-based and Applied Economics

AIEAA
ASSOCIAZIONE ITALIANA DI ECONOMIA AGRARIA E APPLICATA

OPEN ACCESS

Citation: Huber, R., El Benni, N., & Finger, R. (2024). Lessons learned and policy implications from 20 years of Swiss agricultural policy reforms: A review of policy evaluations. *Bio-based and Applied Economics* 13(2): 121-146. doi: 10.36253/bae-14214

Received: January 23, 2023
Accepted: November 20, 2023
Published: July 25, 2024

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Editor: Meri Raggi; Silvia Coderoni

ORCID
RH: 0000-0003-4545-456X
NEB: 0000-0002-3379-2425
RF: 0000-0002-0634-5742

Lessons learned and policy implications from 20 years of Swiss agricultural policy reforms: A review of policy evaluations

Robert Huber[1,*], Nadja El Benni[2], Robert Finger[1]

[1] *Agricultural Economics and Policy ETH Zürich, Switzerland*
[2] *Federal Research Station Agroscope, Tänikon, Switzerland*
*Corresponding author. E-mail: rhuber@ethz.ch

Abstract. Learning from the experiences of other countries can support efforts to improve agricultural policies. Switzerland provides an interesting case because its policy is exceptionally targeted towards the establishment of sustainable production systems. We describe the history and the current state of Swiss agricultural policy, review evaluations of policy reforms, summarise their impact and outline the lessons learned for policy developments in other countries. We discuss four implications: i) some goals have been met, albeit at a high cost, and so, increasing efficiency of policies is key; ii) there is a need for more coherence and coordination regarding the different policy programmes (i.e. in the sense of a 'food system policy'); iii) cross-compliance measures (i.e. minimum standards for receiving support) have an important leverage effect; and iv) policy differentiation (e.g. by spatial targeting) and increasing farmers' discretion over how to achieve goals (e.g. by implementing results-based payments) are key for future policies.

Keywords: agricultural policy, comparative studies, policy comparison, policy evaluation, agriculture and food policy, farm support.
JEL codes: Q01, Q18, Q57.

1. INTRODUCTION

Agricultural policies are essential in achieving a sustainable and resilient farming sector. Agricultural policy goals and instruments have high heterogeneity across nations, which reflects the different historical developments of and fundamental differences in societal needs with regard to agricultural policies worldwide (Swinnen, 2018). Policy learning from the experiences of other countries provides an important entry point for improving agricultural policymaking. Switzerland, which is geographically situated in the heart of Europe but not part of the European Union or the European Common Agricultural Policy (CAP), provides an interesting case for policy learning.

Agricultural policy in Switzerland is characterised by its strong governmental support. The producer support estimate for Swiss agriculture is about 50%, which implies that half of farmers' gross receipts are based on public

Firenze University Press | www.fupress.com/bae

support (OECD, 2022). The total amount of governmental spending is approximately 4 billion Swiss francs (CHF)[1] per year for about 50,000 farms and a total agricultural area of 1.04 million hectares (FOAG, 2022b). The total cost for taxpayers and consumers in 2022 amounts to roughly CHF130,000 per farm per year, or about CHF6000 per hectare of agricultural land per year.

In addition, Swiss agricultural policy has been a forerunner in environmental and animal welfare programmes. In 2022, about 40% of direct payments to Swiss farmers are targeted towards biodiversity conservation, landscape maintenance, sustainable production systems and animal welfare. Swiss agriculture's high level of support for environmental and animal welfare programmes, and its unique policy interventions in Europe, provides a valuable example for policy learning. This is especially so, given the plans to improve environmental performance in the CAP (e.g. via the Farm to Fork strategy; (e.g., Schebesta & Candel, 2020) and by the UK as it tries to make its agricultural policies "greener" (e.g., Gravey, 2019).

In this paper**,** we present and analyse the goals and instruments of Swiss agricultural policy. We also describe the historical development and implementation of the policy and outline its effectiveness by reviewing policy evaluations over the last 20 years. We discuss the lessons learned from Swiss agricultural policy to provide insight for other countries, including not only the positive aspects that should be followed but also the negative ones that are better avoided. On this basis, we derive the implications of Swiss agricultural policy development that may have promise in other farming contexts and environments.

The design and development of Swiss agricultural policy has previously only partly been described (e.g., Curry & Stucki, 1997; El Benni & Lehmann, 2010; Mann, 2003; Mann & Lanz, 2013; Schmid & Lehmann, 2000). In its latest review of Swiss agricultural policy, in 2015, the OECD focused on recommending how to develop further existing policies on a strategic level (OECD, 2015). Since then, no overview has been provided of the most recent reform steps that aim to make Swiss agriculture more ecologically sustainable. Other agricultural policy reviews and comparisons, such as those between the EU and the US (Baylis, Peplow, Rausser, & Simon, 2008; Blandford & Matthews, 2019) and between the CAP and individual countries, such as the UK after Brexit (e.g., Roederer-Rynning & Matthews, 2019), have provided insightful descriptions of ongoing policy changes. In this context, countries that want to support more environment- and animal-friendly multifunctional agricultural sectors can gain insights from the experiences drawn from Switzerland's highly complex agricultural policy (e.g. 104 different direct payment measures are currently implemented), its specific policy programmes and their synergies and trade-offs.

Our analysis presents and discusses the lessons learned from Swiss agricultural policy approaches and provides implications for potential agricultural policy development in Switzerland and other (European) countries. Our contribution focuses on three aspects that extend the current literature on agricultural policy learning. First, we present details and experiences of a wide range of instruments within a multifunctional agricultural landscape and review a (almost) complete set of existing agricultural policy measures that have been applied. Such a comprehensive analysis provides a unique perspective on the fact that agricultural policy is more than the sum of its parts. Second, the recent shift in Swiss agricultural policy towards environmental and animal welfare goals and tailored policy instruments may be exemplary for future European agricultural policy development (Schebesta & Candel, 2020).[2] Despite such efforts, Switzerland is currently observing an increase in societal discourses that have revealed gaps between societal demand for what agricultural and food systems should deliver, especially in terms of environmental performance and animal welfare, and what the current policies allow them to reach (e.g. Huber & Finger, 2019). It is likely that this is also emerging in other countries. Third, Switzerland covers a large gradient of natural environments, from Alpine regions to hilly landscapes and highly productive plains, and thus represents an interesting case for analysing the potential of differentiated policy measures within an agricultural policy mix. The results from our analysis provide important entry points for the discussion of policy instruments and the transformation of food and agricultural policies not only for Switzerland but also for other countries.

The remainder of this paper is structured as follows. We begin by describing the historical development of Swiss agricultural policy. In the second section, we provide an overview of the current goals, programmes, and instruments of Swiss agricultural policy. In the third section, we provide an overview of the goals achieved from the different policies and discuss the effectiveness and efficiency of the various policy measures, based on a review of Swiss agricultural policy evaluations. We then synthesise the impact of the different policies, dis-

[1] Numbers refer to the year 2021. In 2023 1 Swiss franc (CHF) equals ca. 1.05 euro and 1.11 US dollar.

[2] We do not provide an explicit comparison between Swiss agricultural policy and the CAP beyond a short description of their historic development (see the supplementary material)

cuss the lessons learned and present the implications for policy-making and potential learnings to other country-specific agricultural policies.

2. HISTORICAL DEVELOPMENT OF SWISS AGRICULTURAL POLICY TO DATE

2.1. Protective policies in the twentieth century

Governmental regulation of the Swiss agricultural sector started at the beginning of the twentieth century. The evolution of a new "food regime" at the start of the previous century, when farmers were increasingly integrated into the industrialising world and dependent on trade as well as mechanical and chemical inputs (Tauger, 2020), had triggered various laws aiming to protect Swiss farmers from low producer prices due to imports, reduce their debt and maintain their production capabilities. After the world wars, a new constitutional article defined a liberal economic policy in Switzerland – albeit with the exception of the agricultural sector. This "exceptionalism" provided a new legal basis for protective policies. The subsequent 35-year phase (1950–1985) was characterised by protective market regulations for grain, milk and sugar, during which Switzerland became the greatest supporter of agriculture worldwide (Huber & Finger, 2019). The producer support estimate PSE – that is, the transfer from taxpayers and consumers to farmers – was at about 75% in the mid-1980s. This implies that three-quarters of agricultural gross receipts came from either market protection or other forms of price support (OECD, 2015).

2.2. The era of decoupling

The flipside of this massive support until the beginning of the nineties was that the Swiss government spent almost CHF 2 billion to guarantee high farm-gate prices and sell production surpluses from domestic overproduction on international markets, while increasing environmental awareness brought to light the severe environmental problems of this highly intensive production system. At the same time, the negotiations in the Uruguay round of the General Agreement on Tariffs and Trade, and the subsequent foundation of the World Trade Organization (WTO), placed additional pressure on Swiss border protection measures and level of support for producers. This domestic and international pressure led to a major change in Swiss agricultural policy in the 1990s as Switzerland adapted its federal constitution to public and international demands and income and price policies were decoupled. This decoupling was implemented in two successive reform steps. The first of these was in 1992, when Switzerland rejected economic integration with the European Union but decided to pursue a route of agricultural policy reform combined with bilateral agreements, especially with other European countries (El Benni & Lehmann, 2010). Price support was reduced, and decoupled direct payments were introduced for all farmers without geographical restrictions. In addition, farmers could voluntarily apply to a so-called integrated production programme,[3] for which additional payments were provided (Finger & El Benni, 2013).

With the next reform step, in 1999, price guarantees (e.g. for crops and milk) were abolished. Governmental spending was converted into direct payments, and tariff-rate quotas were introduced that complied with WTO rules. Direct payments were divided into general (lump-sum area payments) and ecological direct payments. To be eligible for these direct payments, cross-compliance measures were introduced that guaranteed a minimum environmental and social standard across all farms. Farmers located in hilly and mountainous regions additionally received payments to compensate for unfavourable production conditions and thus maintained production and concurrent landscape maintenance in remote mountain areas. While the first reform step, in 1992, was legally based on two articles, 31a and 31b, newly introduced into agricultural law, the regulatory change in 1999 was based upon the new Article 104 of the federal constitution, which had been accepted in a public vote in 1996.

Article 104 (see the box in the online supplementary material A) defined multifunctionality as the underlying justification for public support of agriculture (Hediger, 2006) and led to a stable political phase between 1999 and 2015. Decoupling shifted the financial burden for agricultural support from the consumer (via consumer prices) to the state, and thus the taxpayer (via tax money used for direct payments). Switzerland's new constitutional article explicitly foresaw a periodic examination of the agricultural policy strategy. The annual federal budget for the agricultural sector, amounting to around CHF 4 billion (approximately 7% of total governmental spending) had to be approved every four years by the Swiss parliament.

This recurrent review of the Swiss agricultural policy led to four consequent reform steps named after the targeted years of the reforms (AP02, AP07, AP11 and

[3] In addition, farmers founded the private food label organisation Integrated Production (IP Suisse) with the goal to align agricultural production with environmental principles such as farm nutrient balance, diversified crop rotation, soil protection and the targeted application of pesticides.

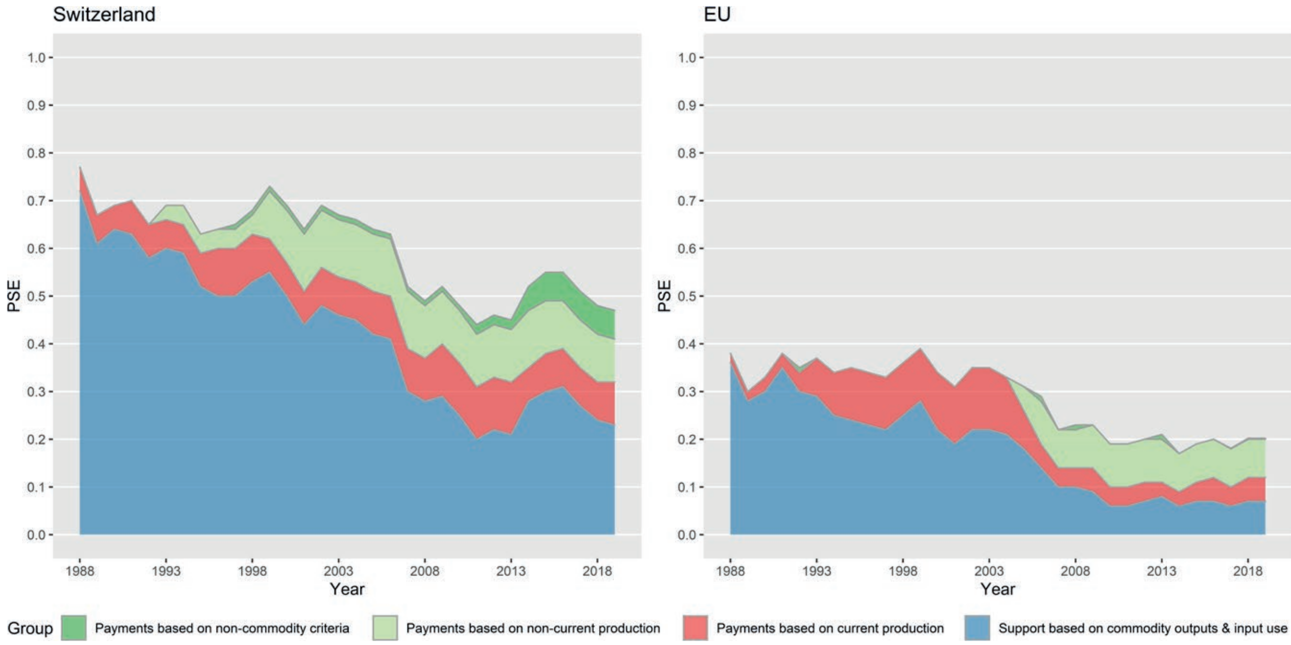


Figure 1. Comparison of producer support estimates (PSE) between Switzerland and the EU. Data from OECD (2022). The different colours refer to the gradient of coupling between the policies and agricultural commodity output. The instruments represented in green are fully decoupled from agricultural production (e.g. a biodiversity conservation programme). Light green refers to support that is not linked to current output (e.g. area-based payments for landscape maintenance). Red refers to payments coupled to production (e.g. area-based payments for a specific crop, such as sugar beet). Blue refers to support that is coupled to commodity outputs or input use.

AP14–17). Policy developments in this period were in line with the reform agenda, including various deregulation and liberalisation steps, e.g. the bilateral trade agreement on cheese with the EU and abolition of milk quotas (El Benni & Lehmann, 2010). During this time, the development of agricultural policy was dominated by the administration and the executive (Hirschi, Widmer, Briner, & Huber, 2013). Overall support and protection decreased slightly, and the producer support estimate amounted to about 50% in 2021, compared to around 18% in the European Union (see Figure 1).

2.3. Increasing societal pressure triggers more environmental sustainability and animal welfare

In Switzerland, citizens can influence public policy via plebiscites. Popular initiatives allow any citizen to launch a proposal to revise the Federal Constitution. In the period from 2016 to 2022, ten popular initiatives were launched that addressed agricultural policy issues, including food security, food sovereignty, speculation on foodstuffs, fair-trade and animal welfare and pesticides. As a result of these, two opposite societal concerns collided. On the one hand, farmers' organisations wanted to re-introduce protective measures (e.g. stricter import restrictions, higher governmental market control); on the other, Swiss citizens criticised the fact that agriculture had not been meeting its environmental and animal welfare goals. The increase in popular initiatives represented a shift from a government-driven process towards "grass-roots initiatives" that had been developed and articulated outside, or in addition to, the legislative and executive processes. This phenomenon revealed an increasing gap between societal demand and the policies and plebiscites, which could be seen as a barometer of the changes in societal preferences for agriculture and related policies (Huber & Finger, 2019). While nine out of ten popular initiatives had been rejected by Swiss voters, they still had a considerable impact on the development of Swiss agricultural policy by putting environmental issues at the top of the agenda (Finger, 2021; Schmidt, Mack, Möhring, Mann, & El Benni, 2019). The pressure led, for example, to the introduction of a new constitutional article (104a) in 2017 that evolved from a counter proposal to a popular initiative that extended the role of agricultural policy towards a more comprehensive "food system policy". Moreover, even though the latest reform process in Switzerland had been delayed (AP22+), the public pressure had still led to a strengthening of agricultural laws on pesticide use and nitrogen policies. More precisely, from 2023 onwards, agricultur-

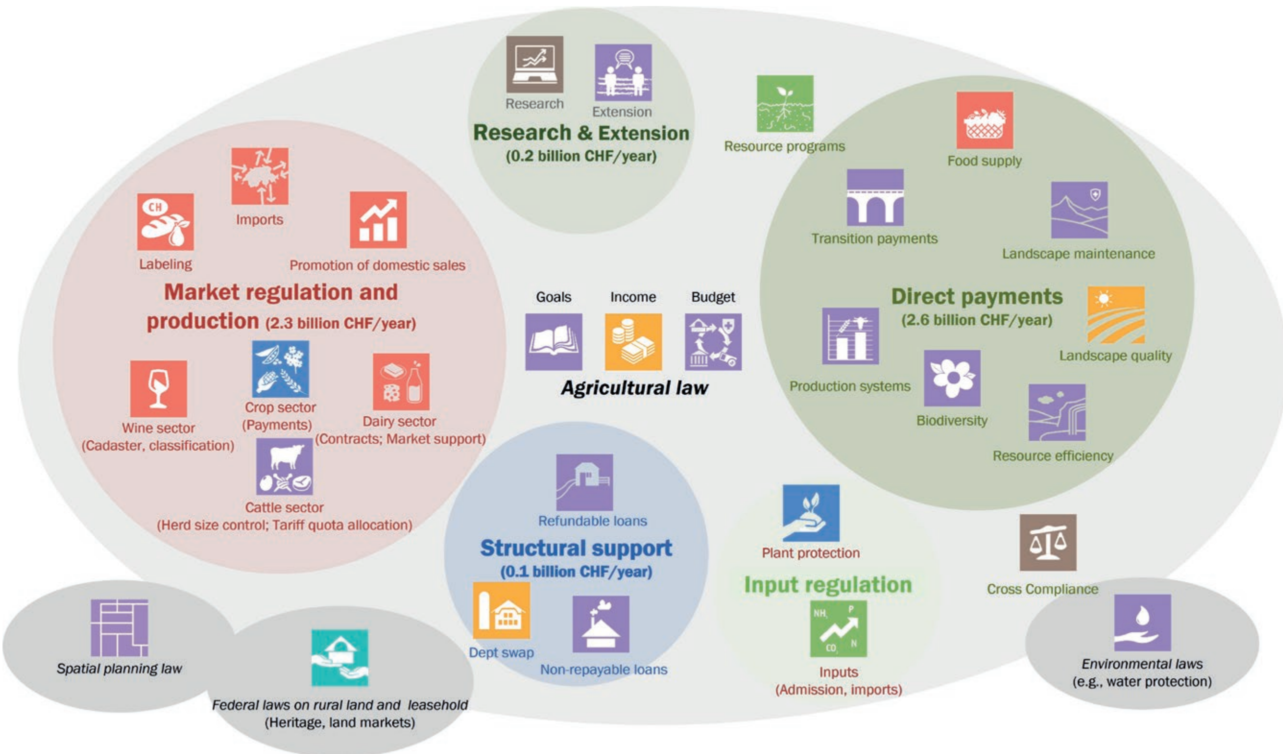


Figure 2. Overview of Swiss agricultural policy, including major legal fundamental agricultural law, federal law on rural land, law on leasehold, spatial planning law and environmental law (grey circles). Financial support to farmers is mainly provided through the agricultural law, whereas the other laws include command-and-control regulations. Major instrument categories within Swiss agricultural law are the direct payment system (green), input regulation (light green), research and consulting (dark green), market regulation and production (red) and structural support (blue). Icons reflect the major policy programmes in these areas. The numbers in CHF are monetary transfers from consumers and taxpayers to farmers per year, which have been stable since 2010. The figure has been adapted from Huber (2022). Please note that the bubbles are for illustrative purpose only and do not represent the (monetary) size of the respective law area.

al policy aims to reduce nitrogen and phosphorus surpluses by 20% until 2030, and the risks associated with the use of plant protection products should be halved by 2027 (FOAG, 2023).[4]

Swiss agricultural policy and the CAP have very similar roots and goals, and they developed on par with respect to the decoupling of income and price policies (see online supplementary information B). However, Swiss agricultural policies have on average gone further than those of the EU with respect to aspects of environmental and animal welfare (see e.g., Metz, Lieberherr, Schmucki, & Huber, 2020; Pe'er et al., 2014). The question is whether and how other countries could learn from the Swiss experience to better consider environmental challenges in agricultural policymaking (Alons, 2017; Pe'er et al., 2020).

[4] These targets are, however, still discussed in the ongoing political process of the AP22+.

3. CURRENT PROGRAMMES AND INSTRUMENTS IN SWISS AGRICULTURAL POLICY

Swiss agricultural policy is a sectoral policy at the federal level. The main regulations are concentrated within a few laws with little linkage either to each other or to cross-sectoral policy areas such as regional, environmental and climate policy (Figure 2). In the following, we summarise the overarching goals of Swiss agricultural policy and describe its interventional logic. We then present two key policy instruments of the agricultural law, namely direct payments, and market regulation. Details of the other policy programmes in the agricultural law (that is structural support, input regulation and research and education) are presented in the online supplementary material C.

3.1. Policy goals and interventional logic

The goals of the Swiss agricultural policy are derived from the federal constitution (see online supplementary

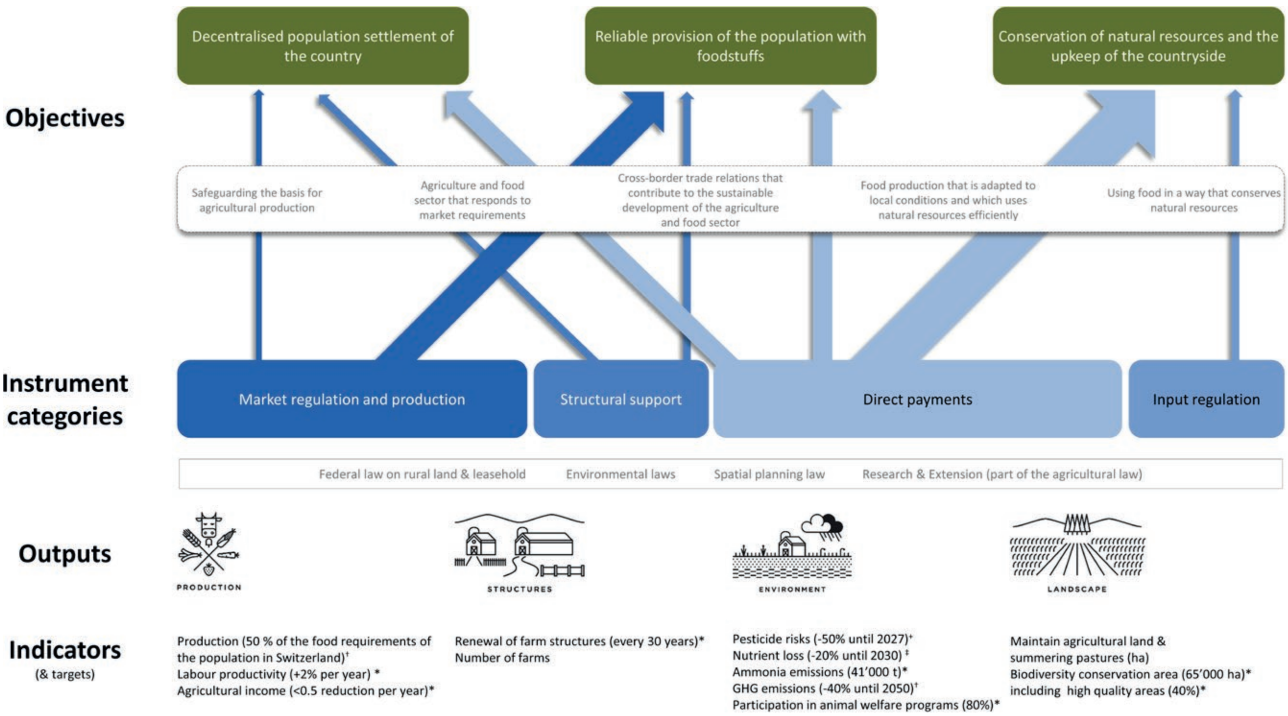


Figure 3. The basic intervention logic summarising the different and overlapping links between the policy goals, main instrument categories, outputs, and indicators in the Swiss agricultural law. The goals of Article 104 are in green; the additional goals of Article 104a are in the white dashed box; instruments with higher impacts on production are in darker blue. Other laws as well as research and extension are depicted as basis or supporting categories. Sources for indicators and target values: ‡FOAG (2022a); +FOAG (2023); †FOAG, BLV, and BAFU (2023) *FC (2020) with reference to the year 2021. Please note that the bars and arrows are for illustrative purpose only and do not represent the (monetary) size of the respective instrument. Formulation of the goals are taken from the original translation of the Federal Constitution of the Swiss Confederation (admin.ch).

material A). There are two key elements: First, the article defines the multifunctional role of agriculture; that is, the agricultural sector should contribute towards a) the reliable provision of foodstuffs to the population, b) the conservation of natural resources and upkeep of the countryside and c) the decentralised population settlement of the country. This implies that the agricultural sector not only has a role as a producer of food but also as a steward of the environment and a key player in rural development. Second, the constitution states that these goals should be achieved by means of a sustainable and market-orientated production policy. In principle, this reflects the main intervention logic[5] (see Figure 3) and the idea of decoupling income and price support in the agricultural sector; that is, market prices should be based on the principle of economic freedom, whereas the confederation can supplement incomes by means of direct subsidies. It is important to note, however, that market-orientated production does not imply fully liberalised and deregulated markets. To fulfil the goal of ensuring food supplies, Swiss agricultural policy directly and indirectly supports market prices, the competitiveness of the agricultural sector and farm structures and rural infrastructure.

Article 104 of the Federal Constitution also predefines four categories of instruments that should be used to achieve these goals (see Figure 3). These main policy categories are i) direct payments to support methods of production that are specifically natural and animal friendly; ii) market regulation to protect farm gate prices and declare the production origin and quality of foodstuffs; iii) structural support (i.e. the provision of investment aids and regulation of the consolidation of agricultural property holdings); and iv) input regulation to protect the environment, e.g. against the excessive use of fertilisers, pesticides and other inputs. The article also provides the basis to support agricultural research, counselling, and education, providing the basis of the Swiss agricultural knowledge system (Obrist, Moschitz, Home, & 2015). Finally, the article provides links to other impor-

[5] An intervention logic links the objective that needs to be met with the policy options that exist.

tant laws, such as the Federal Law on Rural Land and Leasehold and the Environmental Law. The output indicators and the targets of the different policies are set out in various reports of the Federal Office for Agriculture (FOAG, 2022a) and/or the Federal Office for the Environment (BAFU & BLW, 2016), although they are constantly debated and revised as part of political processes.

Article 104a, which was introduced in 2017 through a public vote, strengthens the role of food security formulated in the original 104; that is, it states that the confederation should safeguard the basis for agricultural production by maintaining the extent of agricultural land and guarantee that food production is adapted to local conditions. In addition, the new article also specifies the role of trade in securing food availability by stating that cross-border trade relations should contribute to the sustainable development of the agriculture and food sector. Finally, the article also states that food should be used in a way that conserves natural resources (related to food waste, as an important policy goal).

The clear setting of the linkage between the objectives and instruments shows that Swiss agricultural policies are strongly anchored in the Federal Constitution. The fact that the Swiss public can suggest directly amending the constitution by popular initiatives, and that this democratic tool has been increasingly used in recent years, means that the Swiss constitution can be seen as a "social contract" between the agricultural sector and the rest of the society (see e.g., Feindt et al., 2019).

This brings a high level of legitimacy to the decision-makers on Swiss agricultural policy. On the flipside, the federal constitution is a reservoir of conflicting goals[6] that have led to many practical trade-offs in the implementation of agricultural policy programmes and instruments, as well as their intended outcomes. This is also shown in the basic intervention logic (see Figure 3), illustrating the many overlapping links between the main objectives in the constitution and the four policy categories.

3.2. Direct payments

At the heart of decoupling income and price policies, as well as incentivising the uptake of more sustainable farming practices, is the substitution of price regulations with direct payments that remunerate farmers for their multifunctional role in society. The Swiss agricultural direct payment system has two conceptual pillars. First, payments are conditional on cross-compliance measures. This implies that a farm is only eligible for direct payments if it fulfils minimum environmental requirements (in the so called "proof of ecological performance") and those of individual farmers (e.g. age, education; see online supplementary material C1 for a detailed description of these standards).

Second, the conceptual design of the current direct payment system is inspired by the so called Tinbergen rule, which states that each individual instrument should address a single goal (Mann & Lanz, 2013). This implies that there exists a direct payment programme for each specific goal of Swiss agricultural policy, namely i) ensuring food supply, ii) the maintenance of cultural landscapes, iii) the promotion of landscape quality, iv) increasing resource efficiency, v) biodiversity conservation and vi) the development of environmental- and animal-friendly production systems. The conceptual alignment of the Swiss direct payment programme with the Tinbergen rule aims to ensure that the schemes within the corresponding programme are well-targeted to agricultural policy goals (e.g., S. Wunder et al., 2018). An overview of these payment schemes, and their budgets can be found in Table 1.

In addition to the targeting, each of the programmes may consist of different direct payment schemes and measures, which allows the corresponding direct payments to be "tailored" to production regions, farm types or landscape elements, which should ensure the additionality[7] of the policy (e.g., Guerrero, 2021). For example, the development of a nature- and animal-friendly production system contains payments for organic farming, crop production with restricted use of pesticides, animal welfare and reducing concentrated feed in milk and meat production. Each of these schemes, in turn, consists of different measures (i.e. payments tailored to crops or livestock units). Overall, the Swiss direct payment system consists of 104 different payments.[8]

The design and legal development of direct payments is driven by national authorities, while the responsibility for their administration (control, pay-out, cuts etc.) lies within the Swiss cantons. Thus, the subsidiarity of Swiss agricultural policy is rather low.

3.3. Market Regulation

Market regulations in Switzerland are based on the following four pillars: i) the regulation of imports, ii) the

[6] Switzerland does not have a constitutional court, and conflicting articles may be added to the constitution.

[7] Additionality implies that the direct payment improves environmental outcomes compared to the baseline (e.g., business as usual).

[8] Note that these payments are often characterised by complex substructures and conditions, so the complexity is even higher than the 104 payment schemes.

Table 1. Overview of direct payments in Swiss agriculture (as of 2022).

Objective	Payment for…	No. of measures	Measures tailored to…	Design	Budget (million CHF)	Share (2021)
Ensuring food supply	Producing food on agricultural land	8	Production zones (decreasing with altitude); lower payments for areas under the biodiversity scheme; additional payment for crop rotation area	Action-based scheme (payment per ha of agricultural land)	1078	39%
Landscape maintenance	Cultural landscapes	5	Production zones (increasing with altitude; zero for lowlands)	Action-based scheme (payment per ha of agricultural land)	140	5%
	Steep slopes and very steep slopes	7	Different gradients of steepness (and specific payments for grapes)	Action-based scheme (payment per ha of agricultural land)	149	5%
	Summering pastures	6	Specific animals (cattle v sheep) and differentiating between farms that send or receive animals for summering	Action-based scheme (payment per livestock unit living 100 days on summering pastures)	239	9%
Biodiversity conservation	Areas that support biodiversity maintenance	17	Production zones and type of biodiversity element or measure (e.g. less intensively used grassland, flowering fallows, trees)	Action-based scheme (payment per ha; elements like trees are converted on a ha basis)	159	6%
	Areas that support biodiversity of high quality	17	Production zones and biodiversity elements. No payments for measures on cropland	Result-based scheme (payment per ha for a certain quality, i.e. minimal number of rare species found)	163	6%
	Agglomeration bonus	6	Production zones and biodiversity elements	Collaborative payment scheme (payment per ha)*	113	4%
Landscape quality	Landscape quality	4	Project goals (i.e. ecological elements or land-use types)	Collaborative payment scheme (payment per ha or livestock unit on summering pastures)*	147	5%
Sustainable production systems	Organic agriculture	3	Crops (vegetables and grapes, other crops and grassland)	Action-based scheme (payment per ha)	67	2%
	Extensive production of cereals	1	-	Action-based scheme for crop production without pesticides, except for herbicides (payment per ha)	36	1%
	Grassland-based milk and meat (GMF)	1	-	Action-based scheme that restricts the concentrated use of roughage-consuming animals and the proportion of maize silage from arable land (payment per ha of grassland)	112	4%
	Animal-friendly housing systems	3	Animal type (pigs, poultry, cattle and sheep/goats)	Action-based scheme (payment per livestock unit)	98	3%
	Animals under free-range production systems	7	Animal type	Action-based scheme (payment per livestock unit)	198	7%
Resource efficiency	Agricultural practices	19	Agricultural practices (direct sowing, precision agriculture techniques, wash-up systems in pesticide applications, reduced nitrogen in feed for pigs)	Action-based scheme (payment per ha or livestock unit)	43	2%
Total		104			2'732	100%

*Farmers receive a bonus payment on top of the action-based payment if they designate land for conservation that is in close proximity to neighbours' conservation areas. Eligibility depends on the project (defined by farmers, cantons, farm advisors and members of ecological planning firms). Data are from OECD PSE (OECD, 2022). For details of the different payments, refer to the online supplementary material C2. Note that in 2023, there have been further adjustments in direct payment schemes (e.g. Mack, Finger, Ammann, & El Benni, 2023).

Table 2. Overview of total financial support (border protection and governmental spending) for Swiss farmers.

Objective	Instrument	Targeted or tailored to…	Support (million CHF)	Share PSE (2021)
Market price support	Tariffs and tariff rate quotas	Wheat, barley, maize, rapeseed, milk, beef, pig meat, poultry, sheep meat, eggs, other	2447*	41.5%
Multifunctionality (including environmental goals)	Direct payments	See Table 1	2732	46%
Competitiveness	Milk price supplement for cheese production	Milk used to produce cheese	201	9%
	Payments for non-silage feeding of cows	Milk used to produce raw milk cheese	32	
	Payments for commercial milk	Milk used for export products (chocolate, biscuits)	149	
	Area payments	Oilseed cultivation, sugar beet, leguminous crops, grains	77	
	Concession energy prices		65	
Increase demand for domestic products	Promotion of domestic agricultural products	Advertisement of domestic product categories (milk, meat, fruits, vegetables)	67	1%
Structural support	Refundable loans	Stables, young farmer programme, farm diversification	32	2%
	Non-repayable loans	Stables, residential buildings	3	
	Development and maintenance of infrastructure	Water and road infrastructure, ameliorations, regional projects to support local value chains	84	
Support of resource efficiency and sustainability	Payments for innovative projects (resource programmes)	Different agricultural practices or technologies	25	0.5%
Total**			5914	100%
Governmental spending thereof (i.e. federal budget)			3402	58%

Data source: OECD (2022) *Price support measured in OECD indicator (i.e. market price support); that is, annual monetary value of gross transfers from consumers to agricultural producers arise from policy measures and create a gap between domestic producer prices and the reference prices of a specific agricultural commodity measured at the farm-gate level. **Not considered: Transition payments (expiring in 2023; CHF67 million). Total producer support estimate in 2021: CHF6008 (OECD, 2022). Additional governmental support, namely support by cantons (~CHF200 million), research and extension (~CHF227 million) and social contributions (~CHF60 million); cost of public stockholding (~CHF50 million); and administrative costs (~CHF60 million). Total governmental spending: ~CHF4.1 billion. For further details of the different policy programmes, refer to the online supplementary material on C3 (market regulation), C4 (structural support), C5 (input regulation) and C6 (research and extension).

legal principles for the regulation of domestic markets, iii) the regulation of labels and promotion of domestic sales and iv) the specific support of sensitive product markets (crop, wine, cattle, and dairy). These policies create a highly regulated market environment for Swiss farmers and other market actors. In the following, we describe the key policies in each of the four domains.

Border protection was and still is one of the most important instruments in Swiss agricultural policy. With the exception of the free trade agreement for cheese between the European Union and Switzerland (see Finger, Listorti, & Tonini, 2017; Irek, 2022), the import of agricultural products is restricted by tariffs and governed by tariff-rate quotas. Consequently, almost 40% of the total support for Swiss farmers (as measured by the producer support estimate) stems from market price support (see Table 2).

In contrast to imported food, Switzerland does not regulate domestic production under public law. However, it provides a legal basis for private regulations via stakeholders in the food value chain. The federal government delegates market regulations to the members of different food value chains, including producer organisations, food processors, traders, and retailers. These interest organisations (so-called "branch organisations") have the right to determine production volumes, target prices and market-clearing measures. The purpose of these "branch organisations" is to countervail market power abuses by input suppliers, the food industry and retailers and guarantee secure food availability for consumers.

The government also provides a legal basis for the labelling of agricultural products, such as with respect to type of production (organic) or origin (mountain or Alps) and the protected designation of origin (i.e. Appellation d'origine protégée, AOP, and Indication géographique protégée, IGP). These geographical indications allow typical specialties from defined areas to be protected and differentiated and support their competitiveness in domestic and foreign markets (Maye, Kirwan, Schmitt, Keech, & Barjolle, 2016).

Finally, the Swiss government directly regulates and supports specific markets. For example, it subsidises raw milk production that is used for cheesemaking (Finger et al., 2017) and funds compensation payments for milk and cereal production for export commodities. This reduces the costs of domestic food processors in highly competitive markets (cheese, chocolate, biscuits etc.). The government also subsidises the production of specific crops (payments for single crops) to increase their availability on domestic markets with payments per hectare. These crops include sugar beets, oilseeds, fodder crops and pulses for human consumption.

4. EFFECTIVENESS OF SWISS AGRICULTURAL POLICY: WHAT IS THE EVIDENCE?

In this section, we summarise the achievements of these regulations with respect to the economic, ecological, and social aims formulated in the constitution, focusing on the main output indicators (see Figure 3). We rely on a review of agricultural policy evaluations in Switzerland during the last 20 years. Our review is based on a systematic search of two sources. First, we systematically searched for agricultural policy evaluations in the Administration Research Actions Management Information System (ARAMIS) of the Swiss federal government. ARAMIS is a database in which the evaluations of the federal administration are stored. We searched the database using the search term 'agricultural policy' and found 105 studies from 2002 to 2022. We screened these studies and excluded projects and reports that did not i) focus on agriculture; ii) specifically address a policy instrument (e.g. basic research projects) or iii) evaluated correlations between land-use types e.g. extensively managed grasslands and ecological indicators e.g. bird index without focusing on a specific policy program or measure[9]. We found 16 relevant evaluations. Second, we searched for scientific publications that evaluate Swiss agricultural policy instruments. This search in Google Scholar resulted in additional 17 studies. In total, we included 33 evaluations in our review (see Table 3).

4.1. Economic performance: production and income

With respect to the production and economic goals of the Swiss agricultural policy, the outcomes have been mixed. On the one hand, the share of domestic food production of total consumption, (i.e. the degree of self-sufficiency) has been constant[10], with some fluctuations, over the last 20 years, despite a growing population (~20% in this period). Labour productivity has been steadily increasing, driven mainly by farm structural change and constant re-investment in farm structures and production infrastructure. The corresponding policy targets (i.e. calorie production, productivity increase and re-investment) have been met.

Farm incomes have also increased on average during the last 12 years (i.e. the period between 2010 and 2022). Key elements of this income development are border protection and farm size growth, increasing income from per-hectare direct payments. With respect to border protection, tariff rate quotas are the main instruments, which are highly effective in maintaining high farm-gate prices, as shown in different studies e.g. for meat and vegetables, (Loi et al., 2016) or for dairy products, (Hillen & von Cramon-Taubadel, 2019). In addition, the direct payments have become an important source of agricultural income, especially in rural and mountainous regions. Average direct payments amount to CHF2700 per hectare of all agricultural land in 2021.[11] While these payments are targeted towards public goods from agricultural production, they create windfall effects (i.e. increased income), an important and intended side-effect of the direct payment system in Switzerland. In particular, payments for ensuring food supplies, which comprise more than one-third of all direct payments, have a high income transfer effect (A. Möhring & Mann, 2020).

On the other hand, the massive support of agricultural production and farm incomes increases economic inef-

[9] Please note that we still cite some of these studies in the discussion.

[10] Average net self-sufficiency between 2015 and 2020 was 58%. Net self sufficiency i.e. self-sufficiency corrected for fodder imports, was on average 51%.

[11] Total support per ha of agricultural land (i.e., including border protection) amounts to ~CHF6000 (see Introduction). Thus, direct payments alone correspond to roughly 46% of the support (see also Table 2).

Table 3. Policy evaluation studies in Switzerland 2002–2022.

	Evaluation	Instrument	Key findings	Method	Source
1	Biodiversity programme	Payments for biodiversity	Payments increased the biodiversity conservation area. The combination of action- and results-based schemes increased not only average effectiveness but also windfall gains. Payments resulted in a positive return of investment (for the public).	Causal identification (difference in difference approach)	Wuepper and Huber (2022)
2	Biodiversity programme	Payments for biodiversity	Biodiversity promotion areas generally have a greater diversity of species and habitats than control areas. Quantitative targets (i.e. ha enrolled in the program) are met. Quality of biodiversity area (e.g. number of species) are not met, especially in the lowlands.	Monitoring of biodiversity, indicator assessment, regression analysis	E. Meier et al. (2021)
3	Resource programme	Resource programme (RP) and resource efficiency payments (REPs)	The RP is generally well received by those involved. However, the orientation of resource efficiency contributions lacks a clear focus on the impact of the measures promoted. This calls the subsidy into question. RP is more efficient than REPs.	Assessment of legal and governmental documents	EFK (2021)
4	Biodiversity programme	Agglomeration payments	The collaborative development of agglomeration projects is beneficial to increase the weight given to biodiversity by connecting conservation sites in the planning process of bonus payment schemes.	Spatial regression analysis	Huber et al. (2021)
5	Protection of domestic food via labelling	'Swissness' regulation	The Swissness regulation (i.e. regulation of minimal standards to label a product "from Switzerland") did not affect demand or supply of domestic agricultural products.	Assessment of legal and governmental documents, expert survey	Feige, Rieder, Annen, and Roose (2020)
6	Sustainable production system	Support for grassland-based milk production (GMF)	The GMF programme reduces the use of concentrated feed. No short-term effect on ecological outcomes was found. Economic outcomes improved with the programme.	Agent-based simulation model SWISSland	Mack and Kohler (2019)
7	Market integration and efficiency of seasonal tariff rate quotas	Tariff rate quotas (TRQs)	TRQs are effective in protecting domestic production against competing imports but lead to inefficiencies and create rents for importers.	Regression analysis (parity bounds model)	Hillen (2019)
8	Protecting the Swiss milk market from foreign price shocks	Border protection	Prices of tariff-protected dairy products are influenced by price developments in neighbouring countries. This could not be observed for the liberalised cheese market. The qualitative differentiation of Swiss products contributes more to reducing international price pressure than public border protection.	Price transmission analysis	Hillen and von Cramon-Taubadel (2019)
9	Border protection and downstream industries	Border protection	The high market power of up- and downstream industries results in mark-ups for agricultural inputs. More competition, less border protection and regulatory oversight could increase efficiency along the value chain.	Expert assessment	Wey and Gösser (2019)
10	Biodiversity programme	Payments for biodiversity	The biodiversity programme has had an effect, but shortcomings remain (especially with respect to the quality of the biodiversity areas). Implementation of the programme has been satisfactory, albeit with a high administrative burden. Education and training of farmers should be reinforced to increase effectiveness. Coherence with other policy measures should be checked.	Correlational analysis, interviews, case studies	Fontana et al. (2019)

(Continued)

Table 3. (Continued).

	Evaluation	Instrument	Key findings	Method	Source
11	Food supply support	Payment for food supply	Payments for food supply contribute effectively to calorie production and increase farm incomes. Efficiency could be improved by focusing payments on selected crops and fertile soils. The effectiveness of the instrument critically depends on the definition of food security.	Agent-based simulation model SWISSland	A. Möhring, Mack, Zimmermann, Mann, and Ferjani (2018)
12	Biodiversity programme	Agglomeration payments	There was high participation of farmers. The agglomeration bonus, however, did not allow the proportion of qualitatively valuable biodiversity conservation areas to increase (across all production regions). Complex administration was one important barrier.	Interviews, case studies	Jenny, Studer, and Bosshard (2018)
13	Production support of milk	Payment for milk processed into cheese	About two-thirds of the payments made benefit milk producers. The payment directly affects cheese production and exports but also has indirect effects on other dairy products. The findings suggest a net welfare gain from elimination.	Vector autoregressive model, CAPRI (partial equilibrium model)	Finger et al. (2017)
14	Ecological direct payments	Payments for biodiversity and landscape	There is large heterogeneity in provision costs for environmental services. Targeting and tailoring have the potential to increase the efficiency of the current direct payment system.	Cost accounting, interviews, case studies	Huber, Flury, Meier, and Mack (2017),
15	Sustainable production system	Support for grassland-based milk production (GMF)	The GMF programme reduces nitrogen surpluses, although the effect is very small. An increase in payments would have little additivity.	Agent-based simulation model SWISSland	Mack and Huber (2017)
16	Reduction in nitrogen surpluses	Instruments for the evaluation of nitrogen	Single policy instruments (meat tax, fertiliser tax etc.) are not sufficient to reach the targeted reduction in nitrogen surplus. A coherent policy mix is needed.	Agent-based simulation model SWISSland	Schmidt et al. (2017); Schmidt, Mack, Mann, and Six (2021); Schmidt, Necpalova, Mack, Möhring, and Six (2021)
17	Policy evaluation of tariff rate quotas	Border protection (TRQs)	TRQs partly reach their policy objectives, and the policy can therefore be considered to have been partly effective. However, the policy is clearly inefficient. In addition to the volume of the TRQs and the size of the out-of-quota duty, TRQ administration methods also have an important role in this respect.	Econometric time series analysis	Loi et al. (2016)
18	Evaluation of landscape quality payments	Landscape quality payment (LQP)	LQPs have proven to be an effective tool to pay for maintaining and promoting landscape quality. However, there are considerable windfall gains by farmers for measures that they would nevertheless have applied.	Case studies, expert workshops	Steiger, Lüthi, Schmitt, and Schüpbach (2016a)
19	Rural development (vitality and attractiveness of rural landscapes)	Rural development instruments	There was a positive correlation between municipalities with strong agriculture and vitality. Attractiveness showed only a weak negative statistical correlation. The study underlined the importance of agriculture and agricultural policy for rural areas.	Correlational analysis, expert assessment	Suter et al. (2016)
20	Investment aid	Investment support	Between a quarter and a third of the subsidised investment projects would have been implemented in exactly the same way even without the investment assistance; in this respect, they had no impact.	Assessment of legal and governmental documents	EFK (2015)

(Continued)

Table 3. (Continued).

	Evaluation	Instrument	Key findings	Method	Source
21	Measurement of farm size	Farm size regulations (standard labour force, SAK)	The SAK system was shown to be effective when used as an entry criterion through a threshold or as an administrative delimitation measure. However, when used as the sole selection criterion, the SAK system must be rated more critically.	Interviews, expert workshops, case studies	Huber, Meier, and Flury (2014)
22	Effects of agricultural policy reforms and farm characteristics on income risk	Direct payments	Agricultural policy reforms have decreased the variability of farm revenues and household incomes in Switzerland. Hence, the change from market support to decoupled direct payments reduces the income risk of Swiss farmers.	Econometric analysis of accountancy data	El Benni, Finger, and Mann (2012)
23	Investment aid in rural development	Investment aids	Investment aid contributes to the improvement of economic conditions in rural areas, and especially in mountain areas. This effect, however, is only moderate, considering the population of all processing enterprises.	Interviews, expert workshop, case studies	Flury, Gerber, Giuliani, and Berger (2012)
24	Support of summering pastures	Payments and regulations	The regulations for summering pastures are effective. Payments for summering pastures increase the utilisation of the Alps. However, the overall costs of summering may increase due to additional labour and infrastructure needs.	Farm survey, descriptive analysis of census data, expert assessment, agent-based modelling	Lauber, Calabrese, Von Felten, Fischer, and Schulz (2011)
25	Social protection	Investment aids	Instruments are effective. However, only very few farms need them, and thus, the efficiency of the programme is low, given its high administrative burden.	Expert interviews and assessment	Flury and Peter (2011)
26	Ordinance for ecological quality	Payment scheme	Action-based payments were found to have low effectiveness. A replacement with regionally tailored results-based payments was suggested.	Expert assessment, interviews, case studies	Mann (2010)
27	Agri-environmental policy	Cross-compliance standards	The evaluation of the 'proof of ecological performance' with respect to nitrogen (N) and phosphorus (P) showed an overall reduction of diffuse N and P pollution from agriculture. However, the targets (-33% N and -50% P) were not met.	Correlational analysis	Herzog, Prasuhn, Spiess, and Richner (2008)
28	Farm structural change	Regulation of farm succession	The ongoing development of size structure is so slow that it restricts the potential reduction of production costs, which would be important to increase the competitiveness of the farming sector.	Markov-chain simulation	B. Meier, Giuliani, and Flury (2009)
29	Policy-related transaction costs of direct payments in Switzerland	–	An assessment of policy-related transaction costs in the Grisons and Zurich cantons showed that these costs amount to 1.8 % and 2.8 % of the overall payments, respectively. Thus, the direct payments system is characterised by relatively high transfer efficiency.	Interviews, case studies	Buchli and Flury (2006)
30	Conception of the Swiss direct payment system	Direct payments	The experience from decoupling shows that structural change in agriculture is buffered, that the ecological quality of Swiss landscapes is maintained or enhanced and that individual programmes are partly effective.	Expert assessment	Mann (2003)
31	Effect of direct payment system	Direct payments	Direct payments have had their intended effect. Area-based payment increases and stabilises farm income.	Correlational analysis, sector supply model	Mann and Mack (2004)
32	Decentralised settlement of the country	All instruments	The federal government could spend around CHF700 million less each year on the goal of decentralised settlement. This implies that the current agricultural policy is not sufficiently effective with regard to targeting decentralised settlement and social goals.	Correlational analysis, benchmarking	Rieder, Buchli, and Kopainsky (2004)
33	Evaluation of market support (milk, meat and eggs)	Border protection	Border protection has proven effective in protecting the local grain, dairy and meat markets. No effect had been found for the egg market.	Econometric analysis (equilibrium displacement model)	Koch (2002)

ficiencies along three axes. First, border protection creates high costs for domestic consumers and intermediaries, reducing consumer choice and economic welfare (Gray, Adenäuer, Flaig, & van Tongeren, 2017; Hillen, 2019).

Second, the Swiss tariff rate quotas are economically inefficient, in the sense that they increase prices along the whole value chain and not only at the farm-gate level (Loi et al., 2016); they also create rents to downstream actors that would not exist in the absence of the policy (Hillen, 2019). In this context, studies have shown that there could be considerable market power among retailers. An empirical study after the first agricultural reform step in the early 1990s indeed found indications of asymmetric price transmission between produce and retail prices in the pork market (Abdulai, 2002) implying that downstream market actors have market power. An analysis focusing on dairy and cheese production between 2004 and 2018, however, did not find such asymmetric price transmissions from producer to consumer (Hillen, 2021). Even though a direct comparison between these studies is not possible, one potential reason for the absence of asymmetric price transmissions in more recent studies may have been the establishment of "branch organisations" that regulate domestic markets on a private law basis and that lead to very specific levels of protection for products of different types and quality, which reduces asymmetric price transmission (Esposti & Listorti, 2018; Hillen, 2021).

Third, the regulatory environment also slows resource allocation within the sector to more profitable farms. In fact, the governmental support of approximately CHF4 billion is higher than the net sectoral income of roughly CHF3 billion. This implies that capital invested by the government into agriculture does not fully trickle down to the farmers. This is, among others, since farmers are compensated for the (often costly) provision of ecosystem services, but it may also reflect that efficiency gains could be achieved by re-allocating governmental spending. Overall, the high regulatory environment maintains production levels in Swiss agriculture and ensures a certain level of sectoral income at the expense of low competitiveness and high input and consumer prices (Gray et al., 2017).

4.2. Environmental performance: landscape maintenance, biodiversity, resource efficiency and animal welfare

A key characteristic of Swiss agricultural policy is that almost 40% of governmental spending is for voluntary agri-environmental direct payment programmes supporting landscape maintenance, biodiversity conservation and sustainable production systems, including programmes for low-input use, animal welfare[12] and organic agriculture. In addition, there are important cross-compliance measures for the receipt of direct payments. The introduction of these measures clearly reduced some of the negative environmental effects of the agricultural sector and supported positive ones (e.g., Herzog, Jacot, Tschumi, & Walter, 2017). The environmental goals addressed by these payments have been assessed across the following six categories: biodiversity, landscape, greenhouse gas emissions, nitrogen and phosphorus as well as pesticides[13] (BAFU & BLW, 2016).

Biodiversity: There has been an increase in areas for biodiversity conservation, which has positive associations with flora and fauna. This was observed by several scientific field studies focusing on different taxa, such as vascular plants (Aviron et al., 2008; Herzog et al., 2005; Kampmann et al., 2008; Kampmann, Lüscher, Konold, & Herzog, 2012; Knop, Kleijn, Herzog, & Schmid, 2006), arthropods (Albrecht et al., 2010; Aviron et al., 2008), mammals (Zellweger-Fischer, Kéry, & Pasinelli, 2011) and birds (Birrer et al., 2007; Engist, Finger, Knaus, Guélat, & Wuepper, 2023; Zingg, Grenz, & Humbert, 2018; Zingg, Ritschard, Arlettaz, & Humbert, 2019). In addition, flower strips and other ecological elements have had a positive effect on biodiversity and pest management, as shown by different field and experimental studies (Herzog et al., 2017; Tschumi et al., 2016; Tschumi, Albrecht, Entling, & Jacot, 2015).

It is important to note that the Swiss direct payment programme to support biodiversity targets quantitative and qualitative goals (see Mack, Ritzel, & Jan, 2020). Areas enrolled in the biodiversity programme fulfil the quantitative target of 7% of the utilised agricultural area. Of these areas, more than 75% are also enrolled in agglomeration projects. This implies that the quantitative goals (measured in ha) are being met. However, the ecological quality of these areas is still insufficient to reverse or halt biodiversity decline in Switzerland (E. Meier et al., 2021) and that biodiversity is still not in a good state. For example, Engist et al. (2023) showed that there are fewer and less diverse birds in Switzerland than in neighbouring countries. In addition, the biodiversity programme also creates windfall gains for farmers (Wuepper & Huber, 2022).

Landscape: The maintenance of Swiss agricultural landscapes is threatened by two main factors: i) land

[12] Participation in animal welfare programmes is high. For example, in 2020, 60% of animals were kept in animal-friendly housing systems and 80% were under free-range production systems.

[13] Soil protection is an additional goal in Swiss agricultural policy. However, no monitoring programme has been implemented, and the goal achievement cannot be analysed.

abandonment in mountain regions and ii) the loss of agricultural land to settlement expansion in the lowlands. The explicit goal of the direct payments for landscape maintenance is to reduce annual land abandonment by 1400 hectares, or roughly 20% of the current rate. However, land abandonment is not monitored on a regular basis, and thus, an evaluation of the measures remains difficult. The introduction of the payments, however, stabilised the number of animals sent to summering pastures, despite predictions that the reduction would continue (Herzog & Seidl, 2018; Schulz, Lauber, & Herzog, 2018). Land abandonment is therefore much less eminent, compared to in other European mountain regions (Schirpke, Tasser, Leitinger, & Tappeiner, 2022). Finally, the evaluation of the landscape quality payments implied that farmers realise windfall gains with little environmental additionality (Mann et al., 2023; Steiger, Lüthi, Schmitt, & Schüpbach, 2016b).

Greenhouse gas emissions: The amount of greenhouse gas emissions reduced by 11.5% with the introduction of the direct payment system (7.3 million t CO2eq to 6.5 million t CO2eq). The main reasons for this were a reduction in the animal herd and decreasing inputs of mineral nitrogen (Leifeld & Fuhrer, 2005) after the introduction of the cross-compliance standards. Since then, emissions have remained stable, despite the goal to reduce agricultural greenhouse emissions by 40% by 2050 compared to the emission level in 1999 (FOAG et al., 2023).

Nitrogen and phosphorus: The introduction of cross-compliance measures for all Swiss farms reduced the nitrogen and phosphorus pollution of ground and surface water in the first years of the new policy at the beginning of the century (Herzog et al., 2008; Kupper, Bonjour, & Menzi, 2015). Thus, increasing environmental standards for all farms has had a major effect on the overall ecological performance of the agricultural sector. The main leverage came from the regulation that all farms should comply with the balanced use of nutrients (i.e. the annual nitrogen and phosphorus balance needs to be lower than 110% of crop requirements) to receive direct payments. However, from the initial reduction until about 2005, phosphorus and nitrogen surpluses remained constant. By 2020, the total nitrogen surplus amounted to more than 80,000 t. In certain regions in Switzerland with high animal density (see e.g. Spörri, El Benni, Mack, & Finger, 2023), the aerial deposition of nitrogen had risen to above 40 kg per ha per year (Reutimann, Ehrler, & Schäppi, 2022). Beyond the implementation of cross-compliance measures, political efforts to reduce nutrient load in Swiss agriculture have been less successful. For example, the grass-based milk and meat production scheme, which aims to reduce the use of concentrate in roughage-consuming animals, did not reduce nitrogen surpluses but created windfall gains for participating farms (Bystricky, Bretscher, Schori, & Mack, 2023; Mack & Huber, 2017; Mack & Kohler, 2019). The increased share of sustainable production practices such as organic production (Necpalova et al., 2018; Nemecek et al., 2011; Schader et al., 2013; Zimmermann, Baumgartner, Nemecek, & Gaillard, 2011) has also not substantially decreased nutrient load at the sectoral level. The next policy reform targets a reduction of 20% of phosphorus and nitrogen surpluses in Swiss agriculture by 2030, compared to the mean emission levels between 2014 and 2016.

Pesticides: At the beginning of this century, Swiss agricultural policies did not focus explicitly on the risks from pesticides, despite their broad application in all major Swiss crops (de Baan, Spycher, & Daniel, 2015). Policy goals for groundwater pollution (i.e. maximum of 0.1 μg of pesticides per litre of groundwater) have been achieved in the majority of monitoring locations (FC, 2017). In contrast, pesticide loads in small surface water bodies were found to be often above the legal thresholds (Spycher et al., 2018). This triggered societal and political debates and finally new political initiatives such as a national action plan and new direct payment programmes that also included public-private cooperation (e.g., Mack et al., 2023; N. Möhring & Finger, 2022; Schaub, Huber, & Finger, 2020). However, the monitoring and evaluation of these efforts remains a challenge, e.g. due to data availability regarding detailed pesticide use (similar to the EU e.g., Mesnage et al., 2021) and the complex assessment of health and environmental impacts (N. Möhring et al., 2023). The most recent policy goal is to reduce the risks from pesticides by 50% by 2027, compared to the situation in 2012–2015 (Finger, 2021; Mack et al., 2023).

4.3. Social sustainability dimension: decentralised settlement, family farming, income security, administrative burden

Despite farm structural change, agriculture is still an important pillar of Swiss rural economies, especially in the mountain regions (Ecoplan & HAFL, 2016; Flury, Huber, & Tasser, 2013; Rieder et al., 2004). New policy instruments focusing on investment support along the whole rural value chain successfully support the economic viability of many farms (Flury, Abegg, & Jeannerat, 2017). More importantly, while there is a continued discussion about what family farms imply (Guarín et al., 2020), the existing policies support continuous re-investment in farm structures. The mean

Table 4. Assessment of policy reforms, policy implications and lessons learned from Swiss agricultural policy.

Evaluations*	Assessment (what has worked and what not?)	Lessons learned	Implication for future reforms
[7], [8], [11], [13], [17], [22], [31], [33]	Stabilisation of farm gate prices and farm incomes	Policy is effective with respect to maintain farmers' livelihoods. Border protection and direct payments have a high-income transfer effect.	Increases in efficiency needed
[5], [7], [8], [11]	Self-sufficiency maintained despite growing population; production targets (in calories) are met	The farming sector can steadily improve productivity.	
[20], [21], [28], [32]	Slowing of structural change	Public policy maintains small-scale farming structures.	
[1], [5], [7], [8], [9], [13], [16], [17], [31], [33]	High costs for consumer and/or taxpayers	There is low efficiency in public support.	
[19], [21], [24], [25], [31], [32]	Rural viability is maintained, but only with high public spending		
[3], [19]	Many environmental goals with unclear target values or indicators	There is a lack of focus on funding.	Coherence required
[14], [16], [30]	Trade-off between production (in calories) and environmental targets (N, P, GHG etc.)	There is the potential to re-allocate funds (i.e. public funding for public goods).	
[20], [21], [23], [25]	Continuous re-investment in farm structures	Re-investment needs to be aligned with environmental goals.	
[7], [9]	Rents for up- and downstream actors	There is a need for coordination between market and policy interests.	
[6], [16], [27], [30]	Nitrogen, phosphorus and greenhouse gas emissions stable after an initial decrease with policy reform	Forcing farmers to comply with minimal standards has a leveraging effect on the results indictors.	Strengthening cross-compliance
[6], [15], [27], [30]	Environmental targets (i.e. pesticide load or greenhouse gas or ammonia emissions) not met	Increasing standards can help to achieve environmental targets.	
[1], [4], [10], [14], [18], [26], [30]	Biodiversity programme contributes to halting biodiversity loss	Existing targeting and tailoring provide the basis for effective biodiversity conservation.	Supporting differentiation
[1], [2], [10], [12], [24], [26]	Most environmental targets are only met quantitatively (i.e. output indicators) and not qualitatively (i.e. result indicators)	Further efforts are needed to improve the quality of existing biodiversity conservation areas.	
[1], [11], [15], [18], [26]	Programmes supporting environmentally friendly farming create windfall effects	A shift to results-based payments (i.e. increasing farmers' discretion) could increase the efficiency of the programmes.	
[3], [4], [12], [29]	High administrative burden	Digitalisation is needed to reconcile administrative burden and differentiation of policy incentives.	

*The numbers refer to the evaluation sources in Table 3 i.e. [1] Wuepper and Huber (2022); [2] Meier et al. (2021); [3] EFK (2021); [4] Huber et al. (2021); [5] Feige, Rieder, Annen, and Roose (2020); [6] Mack and Kohler (2019); [7] Hillen (2019); [8] Hillen and Von Cramon-Taubadel (2019); [9] Wey and Gösser (2019); [10] Fontana et al. (2019); [11] A Möhring, Mack, Zimmermann, Mann, and Ferjani (2018); [12] Jenny, Studer, and Bosshard (2018); [13] Finger et al. (2017); [14] Huber, Flury, Meier, and Mack (2017); [15] Mack and Huber (2017); [16] Schmidt et al. (2017), Schmidt, Mack, Mann, and Six (2021), Schmidt, Necpalova, Mack, Möhring, and Six (2021); [17] Loi et al. (2016); [18] Steiger, Lüthi, Schmitt, and Schüpbach (2016); [19] Suter et al. (2016); [20] EFK (2015); [21] Huber, Meier, and Flury (2014); [22] El Benni, Finger, and Mann (2012); [23] Flury, Gerber, Giuliani, and Berger (2012); [24] Lauber, Calabrese, Von Felten, Fischer, and Schulz (2011); [25] Flury and Peter (2011); [26] Mann (2010); [27] Felix Herzog, Prasuhn, Spiess, and Richner (2008); [28] B. Meier, Giuliani, and Flury (2009); [29] Buchli and Flury (2006); [30] Mann (2003); [31] Mann and Mack (2004), [32] Rieder, Buchli, and Kopainsky (2004); [33] Koch (2002).

farm size in Switzerland is 21 hectares (FOAG, 2022b). The dualistic development of farm structures (i.e. an increase in very large and small farms combined with a decrease of mid-sized farms) is much less pronounced in Switzerland than in other countries (Bokusheva & Kimura, 2016).

In addition, the restrictive law on rural land has two important implications. First, farm succession in Switzerland is almost exclusively restricted to the descendants of farmers. Second, farms are kept among families to profit from fiscal rewards, zoning decisions or advantages related to living outside the building zone. Thus, most farms that leave the sector are small and at the end of the generational cycle (e.g., Zorn & Zimmert, 2022). Overall, the regulations with respect to structural changes in Swiss agricultural policy have led to high investment on a sector level, despite small farm structures and highly regulated land markets, with the consequence being the family-based and continuous, rather than dualistic, development of farm structures.

While income inequality in Swiss agriculture has increased as a consequence of the decoupling of price and income policies (especially between lowlands and hilly and mountain regions), the introduction of the direct payment system has positively influenced income stability by decreasing the variability of farm revenues and household income in Swiss agriculture (El Benni & Finger, 2013; El Benni, Finger, & Mann, 2012; El Benni, Finger, Mann, & Lehmann, 2012). Even though direct payments also aim to support farm incomes, the income goals of agricultural policies cannot be considered to have been achieved, and off-farm income is an indispensable diversification strategy of Swiss farm households (El Benni & Schmid, 2021). Despite ongoing discussions about the interpretation and measurement of farm incomes (Finger & El Benni, 2021), the strong governmental support has secured stable farm incomes in Swiss agriculture over recent decades. In this context, Zimmert and Zorn (2022), using a spatial regression discontinuity design, showed that direct payments increased family farm employment. The analysis pointed to not only the economic but also the social side-effects of the current direct payment system because the additional labour force often consists of non-salaried female household members. Without a wage, these family members are not sufficiently protected socially, an issue that should gain importance in the discussion on the further development of agricultural policy.

Finally, a flipside of the enforced conditionality of the Swiss direct payments system is that a high administrative burden is placed on both the farmers and the government (Mack, Ritzel, Heitkämper, & El Benni, 2021; Ritzel, Mack, Portmann, Heitkämper, & El Benni, 2020). While the actual costs of monitoring and implementing agricultural policies are less than 5% of the total budget for agriculture, farmers perceive administration to be a burden (El Benni et al., 2022; Mack, Kohler, Heitkämper, & El-Benni, 2019).

5. DISCUSSION: LESSON LEARNED AND IMPLICATIONS FOR FUTURE POLICY DEVELOPMENT

In this section, we discuss findings from our review with respect to the general lessons learned from Switzerland's experience and the following four implications that may provide entry points for the discussion of specific policy design features that would be transferable also to other countries. First, the economic and social goals have largely been met, but the costs for consumers and taxpayers are high (approximately CHF130,000 per farm per year, or ~CHF6,000 per hectare of agricultural land per year). Thus, increasing the efficiency of Swiss agricultural policy is key. Second, programmes and instruments need to be more coherently embedded in the food and agricultural sector not only to reconcile the economic and environmental goals but also to improve collaboration along the value chain. Third, standards for all farms have increased the overall ecological performance of the agricultural sector. Strengthening of cross-compliance measures has the potential to provide valuable leverage and support to the agri-environmental fields that fail to meet their targets. Fourth, differentiating targets (e.g. in space) and increasing farmers' discretion over how to achieve goals provide promising approaches to realise the premise of public funding for public goods.

5.1. Increasing efficiency

One of the key preconditions for the Swiss policy system is its restrictive border protection and generous governmental budget for agriculture. High farm-gate prices and large funds for direct payments have created a system that effectively supports the achievement of some policy targets, such as a food supply, landscape maintenance and contribution to decentralised settlement. The support has also allowed the farming sector to steadily increase labour productivity and to re-invest in small-scale infrastructure (maintaining family-based, peasant farm structures).

However, the efficiency of the system is low, including the payments for ensuring that food supplies are effective in increasing calorie production and for maintaining arable land for crop production (A. Möhring et al., 2018). Up to 25% of these payments could be saved if criteria other than the number of calories produced were considered (e.g. maintaining productive land without calorie targets; (A. Möhring & Mann, 2020). Also, the targeting and tailoring of policies has led to windfall gains for farmers. The design of a biodiversity programme combining different schemes, for example, creates larger windfall effects (Wuepper & Huber, 2022).

This implies that if the programme has additional environmental benefits, the implementation of the corresponding direct payment comes with high public costs. The restricted farm structural change also implies that farms with low competitiveness remain in the sector (Suter et al., 2016).

Thus, increasing efficiency and reducing the windfall effects of agri-environmental instruments would permit funds to be reallocated to more effective instruments and thus boost the environmental impact of agricultural programmes. In its latest assessment of Swiss agricultural policy, the OECD recommended that Switzerland further liberalise its border protection and reduce trade barriers while also reducing the overall level of general direct payments (OECD, 2015). This should allow farmers to respond to market signals, increase their competitiveness and bring about greater efficiency in the Swiss policy approach. How to align market liberalisation and the support of peasant farm structures or the contribution to decentralised settlement in this context is an important topic for future research.

5.2. Improving coherence

The acceptance of conflicting goals and trade-offs in agricultural policy-making creates challenges for policy coherence (Coderoni, 2023; Eyhorn et al., 2019; Mann & Kaiser, 2023). Trade-offs are inherent in the agricultural and food system, and there is no simple strategy that would allow all positive and negative externalities from agricultural production to be disentangled. The key challenge in Swiss agricultural policy is the conflicting goals that lead to trade-offs. This involves, for example, the production goals (measured in calories or degree of self-sufficiency), the maintenance of decentralised peasant farm structures and the environmental targets (reductions in emissions and the support of biodiversity conservation areas). Given the current inefficiencies in supporting the agricultural sector, reallocating funds, and stronger focusing on the principle of "public funding for public goods" could alleviate the trade-offs between these goals (e.g., Bateman & Balmford, 2018; S. Wunder et al., 2018). This includes, for example, that instruments that promote production include sustainability standards or that support investment should be aligned to environmental or animal welfare goals. A better alignment of policies would not make the inherent trade-offs disappear, but it could certainly improve the efficiency of the public money spent on agriculture.

Furthermore, some of the windfall gains from agricultural policy support end up in up- and downstream companies with a vested interest in maintaining protection. Thus, better policy coherence should not only focus on aligning policy instruments but also include the actors along the value chain. In this context, the link between public incentives and private sustainability initiatives (e.g. trough labelling) is key (Poppe & Koutstaal, 2020). For example, the development of a new, pesticide-free standard for wheat production in Switzerland has allowed the creation of synergies between public and private (market) goals, where farmers receive compensation for not using pesticides from governmental direct payments and private price mark-ups (N. Möhring & Finger, 2022).

The political system in Switzerland enables partial policy success for different interest groups when negotiating policy reforms (Metz et al., 2020). Together with public plebiscites on agricultural policy questions (Huber & Finger, 2019), this can have the effect that the resulting policy has to tolerate certain conflicts in the overall policy. Here, the alignment of agricultural policies with more coherent strategies, such as a common food policy that includes a wider range of stakeholders (De Schutter, Jacobs, & Clément, 2020) within specific areas such as pesticides (N. Möhring et al., 2020) and nitrogen use (Kanter et al., 2020) is important . Beyond the integration of stakeholders along value chains, a food system policy could also include demand-side policy instruments for sustainable food consumption (Ammann, Arbenz, Mack, Nemecek, & El Benni, 2023), consider sustainability standards in global agri-food supply chains (e.g., Meemken et al., 2021) or support sustainable public food procurement (e.g., Schleiffer, Landert, & Moschitz, 2022). This could provide the basis to initiate the necessary transformation of the agricultural and food system. In Switzerland, the policy goals formulated in Article 104a provide a constitutional basis for the future development of such a food policy approach that could also be exemplary for other countries.

5.3. Strengthening cross-compliance

Strict cross-compliance measures provide an effective tool to achieve environmental outcomes. While this had also been discussed in the context of the CAP (e.g., Pe'er et al., 2019), the Swiss example clearly shows that the conditionality of payments is effective in reducing negative environmental externalities and increases the provision of positive externalities in agricultural production. The introduction of the proof of ecological performance as cross compliance measure in Switzerland has had a leveraging effect on the environmental performance of Swiss agriculture (Herzog et al., 2008). Stricter conditions for the proof of environmental performance could, under certain market and production scenarios, actually contribute to the better achievement of environmental targets with little reduction in farm incomes (Schmidt et al., 2019).

However, there are also critical aspects that need to be discussed in this context. Increasing production standards via cross-compliance measures might create leakage effects i.e. some stricter regulations would increase the number of non-complying farms—that is, farms that do not receive direct payments but also do not comply with cross-compliance regulations; (Schmidt et al., 2019). While the overall strong support of agriculture in Switzerland attenuates this risk to a certain extent, since farms would lose a considerable amount of their income share, this would be more pressing in countries with lower overall support. This implies that command and control instruments could replace cross-compliance measures, but their implementation would certainly create more opposition in the agricultural sector (Erjavec & Erjavec, 2021). In addition, it could also create leakage of negative environmental effects to other countries if imports were to increase due to the stricter regulation (Bystricky, Nemecek, Krause, & Gaillard, 2020). Finally, our review does not provide a direct comparison of cross-compliance measures between Switzerland and other countries. While some studies have looked at certain commonalities and differences (BAFU, 2023; Baur & Nitsch, 2013; Nitsch & Osterburg, 2005), the extent to which Switzerland, through its experiences with cross-compliance, could serve as a role model for other countries would certainly need additional research.

5.4. Supporting differentiation

The targeting and tailoring of policy incentives in space, time and across farm types allows for the transparent and efficient support of public goods provided by the farming sector. The Swiss case shows the advantages of such policy designs that try to implement the idea of "public funding for public goods". This allows us to differentiate between regions with different production conditions, which is a prerequisite for the successful support of local public goods provided by agriculture, such as landscape maintenance and biodiversity conservation (Gawith & Hodge, 2019; Navarro & López-Bao, 2018). In addition, the high degree of targeting and tailoring (in combination with the cross-compliance measures) in the Swiss direct payment system enables attenuation of the tendency of adverse selection into voluntary agri-environmental programmes, which is key for economic incentives for public good provision (e.g., Sven Wunder, Börner, Ezzine-de-Blas, Feder, & Pagiola, 2020).

A step forward in payment differentiation would be to extend the use of results-based incentives (i.e. paying farmers for achieving targets and not for certain aspects of management). Recent studies have shown a promising effect on the effectiveness and efficiency of a more widespread use of such results-based agri-environmental schemes in Switzerland (e.g., Huber, Späti, & Finger, 2023; Huber et al., 2021; Kreft, Finger, & Huber, 2023; Mack et al., 2020; Wuepper & Huber, 2022). These schemes would also enable farmers to use their own discretion over how to achieve outcome goals (e.g., Ehlers, Huber, & Finger, 2021).

The flipside of increasing targeting and tailoring to achieve efficiency gains is more complex systems with potentially high administrative burdens (e.g., El Benni et al., 2022). Here, the use of digital technologies and the digitalisation of entire agricultural policies plays a key role (Ehlers et al., 2022; Ehlers et al., 2021). This could not only reduce the administrative burden but also create new opportunities to measure the outcomes of instruments and thus establish results-based or collective policy schemes that do not have to rely on controls on individual farms.

6. CONCLUSION

There are four implications from these Swiss experiences for policymakers and researchers alike. First, efficiency must be increased to re-allocate funds towards programmes that effectively support the provision of public goods or reduce negative externalities. Second, the coherence of different policy programmes is key. Increasing funds for public goods might be a necessary condition for a more sustainable agricultural sector, albeit one that is not sufficient. The Swiss case shows that the coordination of policies along value chains and across sectoral policies and stakeholders (i.e. in the sense of a "food system policy") is indispensable for making agriculture and food production more sustainable. Third, cross-compliance measures (i.e. minimal economic, environmental, and social standards) for receiving governmental support have an important leverage effect. Even though we observed that setting these standards can lead to political conflicts, they have made a decisive contribution to improving the environmental performance of Swiss agriculture. Fourth, the examination of Swiss agricultural policy suggest that some environmental targets can be achieved while allowing for windfall gains from farmers' provision of environmental public goods. Our conclusion is not that other countries should also apply programmes with low additionality, especially given the fact that they might face much stricter budget constraints, but a carefully differentiated agri-environmental policy programme that focuses on landscape, biodiversity, animal welfare and ecosystem services should also allow for maintaining economic viability and rural incomes.

Our review and the derivation of the lessons learned imply two important research gaps. First, more studies that effectively provide scientific evidence for policymakers are needed (El Benni, Grovermann, & Finger, 2023). Special emphasis shall be on scientifically sound approaches for policy evaluation, including increased attempts to estimate the causal effect of policies. This is often hampered, however, by the complex regulatory environment and the many interactions between programmes and instruments that are often introduced at the same moment in time. Second, future research could focus on the transferability of these lessons, especially with respect to the specific effect of policy mixes and how an integrated policy framework could alleviate trade-offs in the joint provision of food and ecosystem services. Our review is context-specific, and we cannot draw direct implications for other countries (e.g. for countries with lower financial resources to support agriculture). However, the implications from the lessons learned in Swiss agricultural policy have been mirrored in many ongoing proposals on how to improve the CAP (e.g., Guyomard et al., 2023; Kelemen et al., 2023; Pe'er et al., 2020). Thus, providing further evidence will also be of value beyond Switzerland.

7. REFERENCES

Abdulai, A. (2002). Using threshold cointegration to estimate asymmetric price transmission in the Swiss pork market. *Applied Economics, 34*(6), 679-687. https://doi.org/10.1080/00036840110054035

Albrecht, M., Schmid, B., Obrist, M. K., Schüpbach, B., Kleijn, D., & Duelli, P. (2010). Effects of ecological compensation meadows on arthropod diversity in adjacent intensively managed grassland. *Biological Conservation, 143*(3), 642-649. https://doi.org/10.1016/j.biocon.2009.11.029

Alons, G. (2017). Environmental policy integration in the EU's common agricultural policy: greening or greenwashing? *Journal of European Public Policy, 24*(11), 1604-1622. https://doi.org/10.1080/13501763.2017.1334085

Ammann, J., Arbenz, A., Mack, G., Nemecek, T., & El Benni, N. (2023). A review on policy instruments for sustainable food consumption. *Sustainable Production and Consumption, 36*, 338-353. https://doi.org/10.1016/j.spc.2023.01.012

Aviron, S., Nitsch, H., Jeanneret, P., Buholzer, S., Luka, H., Pfiffner, L., … Herzog, F. (2008). Ecological cross compliance promotes farmland biodiversity in Switzerland. *Frontiers in Ecology and the Environment, 7*(5), 247-252. https://doi.org/10.1890/070197

BAFU. (2023). *Bundesamt für Umwelt. Kompetenzzentrum Europarecht. Europäisches Umweltrecht und rechtsvergleichende Rechtsgutachten* .https://www.bafu.admin.ch/bafu/de/home/themen/recht/kompetenzzentrum-europarecht.html

BAFU, & BLW. (2016). Umweltziele Landwirtschaft. Statusbericht. 2016. Bundesamt für Umwelt, Bern. Umwelt-Wissen Nr. 1633: 114 S.

Bateman, I. J., & Balmford, B. (2018). Public funding for public goods: A post-Brexit perspective on principles for agricultural policy. *Land Use Policy, 79*, 293-300. https://doi.org/10.1016/j.landusepol.2018.08.022

Baur, P., & Nitsch, H. (2013). *Umwelt- und Tierschutz in der Landwirtschaft: Ein Vergleich der Schweiz mit ausgewählten europäischen Ländern unter besonderer Berücksichtigung des Vollzugs. Studie im Auftrag des Bundesamtes für Landwirtschaft BLW*.

Baylis, K., Peplow, S., Rausser, G., & Simon, L. (2008). Agri-environmental policies in the EU and United States: A comparison. *Ecological Economics, 65*(4), 753-764. https://doi.org/10.1016/j.ecolecon.2007.07.034

Birrer, S., Spiess, M., Herzog, F., Jenny, M., Kohli, L., & Lugrin, B. (2007). The Swiss agri-environment scheme promotes farmland birds: but only moderately. *Journal of Ornithology, 148*(2), 295-303. https://doi.org/10.1007/s10336-007-0237-y

Blandford, D., & Matthews, A. (2019). EU and US Agricultural Policies: Commonalities and Contrasts. *EuroChoices, 18*(1), 4-10. https://doi.org/10.1111/1746-692X.12217

Bokusheva, R., & Kimura, S. (2016). Cross-Country Comparison of Farm Size Distribution. https://doi.org/10.1787/5jlv81sclr35-en

Buchli, S., & Flury, C. (2006). Vollzugs-und kontrollkosten der direktzahlungen. *Agrarforschung, 13*(3), 114-119.

Bystricky, M., Bretscher, D., Schori, F., & Mack, G. (2023). Reducing feed-food competition with direct payments? An ex-ante assessment of economic and environmental impacts. *Q Open*. https://doi.org/10.1093/qopen/qoad002

Bystricky, M., Nemecek, T., Krause, S., & Gaillard, G. (2020). Potenzielle umweltfolgen einer umsetzung der trinkwasserinitiative. *Zürich: Agroscope Science Nr, 99*.

Coderoni, S. (2023). Key policy objectives for European agricultural policies: some reflections about the policy coherence. *Bio-based and Applied Economics*. https://doi.org/10.36253/bae-13971

Curry, N., & Stucki, E. (1997). Swiss Agricultural Policy and the Environment: An Example for the Rest of Europe to Follow? *Journal of Environmental Planning and Management, 40*(4), 465-482. https://doi.org/10.1080/09640569712047

de Baan, L., Spycher, S., & Daniel, O. (2015). Einsatz von Pflanzenschutzmitteln in der Schweiz von 2009 bis 2012. *Agrarforschung Schweiz, 6*(2), 48-55.

De Schutter, O., Jacobs, N., & Clément, C. (2020). A 'Common Food Policy' for Europe: How governance reforms can spark a shift to healthy diets and sustainable food systems. *Food Policy*, 101849. https://doi.org/10.1016/j.foodpol.2020.101849

Ecoplan, & HAFL. (2016). *Beitrag der Landwirtschaft und der Agrarpolitik zur Vitalität und Attraktivität des ländlichen Raums*. Retrieved from Studie im Auftrag des Bundesamts für Landwirtschaft (BLW). Bern.

EFK. (2015). *Eidgenössische Finanzkontrolle. Investitionshilfen in der Landwirtschaft Evaluation der Konzeption, Kosten und Wirksamkeit. Bern.* ww.efk.admin.ch

EFK. (2021). *Eidgenössische Finanzkontrolle. Evaluation of the resource programme and resource efficiency contributions for more sustainable agriculture. Bern.* www.efk.admin.ch

Ehlers, M.-H., Finger, R., El Benni, N., Gocht, A., Sørensen, C. A. G., Gusset, M., … Huber, R. (2022). Scenarios for European agricultural policymaking in the era of digitalisation. *Agricultural Systems, 196*, 103318. https://doi.org/10.1016/j.agsy.2021.103318

Ehlers, M.-H., Huber, R., & Finger, R. (2021). Agricultural Policy in the Era of Digitalisation. *Food Policy, 100*. https://doi.org/10.1016/j.foodpol.2020.102019

El Benni, N., & Finger, R. (2013). The effect of agricultural policy reforms on income inequality in Swiss agriculture - An analysis for valley, hill and mountain regions. *Journal of Policy Modeling, 35*(4), 638-651. https://doi.org/10.1016/j.jpolmod.2012.03.005

El Benni, N., Finger, R., & Mann, S. (2012). Effects of agricultural policy reforms and farm characteristics on income risk in Swiss agriculture. *72*(3), 301-324. https://doi.org/10.1108/00021461211277204

El Benni, N., Finger, R., Mann, S., & Lehmann, B. (2012). The distributional effects of agricultural policy reforms in Switzerland. *Agricultural Economics, 58*(11), 497-509.

El Benni, N., Grovermann, C., & Finger, R. (2023). Towards more evidence-based agricultural and food policies. *Q Open*. https://doi.org/10.1093/qopen/qoad003

El Benni, N., & Lehmann, B. (2010). Swiss agricultural policy reform: Landscape changes in consequence of national agricultural policy and international competition pressure. In J. Primdahl & S. Swaffield (Eds.), *Globalisation and Agricultural Landscapes. Change Patterns and Policy trends in Developed Countries. Chapter 5.* Cambridge University Press (in Press).

El Benni, N., Ritzel, C., Heitkämper, K., Umstätter, C., Zorn, A., & Mack, G. (2022). The cost of farmers' administrative burdens due to cross-compliance obligations. *Journal of Environmental Planning and Management, 65*(5), 930-952. https://doi.org/10.1080/09640568.2021.1920376

El Benni, N., & Schmid, D. (2021). Off-farm income and direct payments—an indispensable diversification strategy of Swiss farmers. *Q Open, 2*(1). https://doi.org/10.1093/qopen/qoab019

Engist, D., Finger, R., Knaus, P., Guélat, J., & Wuepper, D. (2023). Agricultural systems and biodiversity: evidence from European borders and bird populations. *Ecological Economics, 209*, 107854. https://doi.org/10.1016/j.ecolecon.2023.107854

Erjavec, K., & Erjavec, E. (2021). Framing agricultural policy through the EC's strategies on CAP reforms (1992–2017). *Agricultural and Food Economics, 9*(1), 5. https://doi.org/10.1186/s40100-021-00178-4

Esposti, R., & Listorti, G. (2018). Price Transmission in the Swiss Wheat Market: Does Sophisticated Border Protection Make the Difference? *The International Trade Journal, 32*(2), 209-238. https://doi.org/10.1080/08853908.2017.1345668

Eyhorn, F., Muller, A., Reganold, J. P., Frison, E., Herren, H. R., Luttikholt, L., … Smith, P. (2019). Sustainability in global agriculture driven by organic farming. *Nature Sustainability, 2*(4), 253-255. https://doi.org/10.1038/s41893-019-0266-6

FC. (2017). *Federal Council. Aktionsplan zur Risikoreduktion und nachhaltigen Anwendung von Pflanzenschutzmitteln. Bericht des Bundesrates.* Retrieved from https://www.newsd.admin.ch/newsd/message/attachments/49600.pdf

FC. (2020). *Swiss Federal Council. Botschaft zur Weiterentwicklung der Agrarpolitik ab 2022 (AP22+). Bern.*

Feige, S., Rieder, S., Annen, R., & Roose, Z. (2020). *Evaluation der «Swissness» im Lebensmittelbereich. Schlussbericht zuhanden des Bundesamts für Landwirtschaft. htp St. Gallen und Interface Politikstudien Forschung Beratung.* Retrieved from https://www.aramis.admin.ch/Grunddaten/?ProjectID=41629

Feindt, P. H., Krämer, C., Früh-Müller, A., Heißenhuber, A., Pahl-Wostl, C., Purnhagen, K. P., … Wolters, V. (2019). *Ein neuer Gesellschaftsvertrag für eine nach-*

haltige Landwirtschaft : Wege zu einer integrativen Politik für den Agrarsektor: Springer Nature.

Finger, R. (2021). No pesticide-free Switzerland. *Nature Plants, 7*(10), 1324-1325. https://doi.org/10.1038/s41477-021-01009-6

Finger, R., & El Benni, N. (2013). Farmers' adoption of extensive wheat production: Determinants and implications. *Land Use Policy, 30*(1), 206-213. https://doi.org/10.1016/j.landusepol.2012.03.014

Finger, R., & El Benni, N. (2021). Farm income in European agriculture: new perspectives on measurement and implications for policy evaluation. *European Review of Agricultural Economics, 48*(2), 253-265. https://doi.org/10.1093/erae/jbab011

Finger, R., Listorti, G., & Tonini, A. (2017). The Swiss payment for milk processed into cheese: ex post and ex ante analysis. *Agricultural Economics, 48*(4), 437-448. https://doi.org/10.1111/agec.12345

Flury, C., Abegg, C., & Jeannerat, H. (2017). *Zwischenevaluation «Projekte zur regionalen Entwicklung». Bericht zuhanden des Bundesamts für Landwirtschaft*. Retrieved from https://www.aramis.admin.ch/Grunddaten/?ProjectID=47389

Flury, C., Gerber, A., Giuliani, G., & Berger, S. (2012). Evaluation der wirtschaftlichen Bedeutung und Erfolgsfaktoren regionaler Verarbeitungsbetriebe unter Berücksichtigung der Investitionshilfen. *Flury&Giuliani GmbH, Zürich*.

Flury, C., Huber, R., & Tasser, E. (2013). Future of Mountain Agriculture in the Alps. In S. Mann (Ed.), *The Future of Mountain Agriculture* (pp. 105-126): Springer Berlin Heidelberg.

Flury, C., & Peter, K. (2011). *Evaluation der Effektivität von Betriebshilfemass-nahmen im Zusammenhang mit finanzieller Bedräng-nis und Verschuldung*.

FOAG. (2022a). *Federal Office for Agriculture. Zukünftige Ausrichtung der Agrarpolitik. Bericht des Bundesrates in Erfüllung der Postulate 20.3931 der WAK-S und 21.3015 der WAK-N. Bern*. Retrieved from https://www.blw.admin.ch/blw/de/home/politik/agrarpolitik/postulat.html

FOAG. (2022b). Federal Office for Agriculture. Agrarbericht (diverse Jahrgänge) Retrieved 05.2009, from Bundesamt für Landwirtschaft. Online: https://www.agrarbericht.ch/de. Access date: 01.2023

FOAG. (2023). Federal Office for Agriculture. Verordnungspaket Parlamentarische Initiative 19.475 «Das Risiko beim Einsatz von Pestiziden reduzieren» https://www.blw.admin.ch/blw/de/home/politik/agrarpolitik/parlamentarischeinitiative.html.

FOAG, BLV, & BAFU. (2023). *Klimastrategie Landwirtschaft und Ernährung 2050. Verminderung von Treibhausgasemissionen und Anpassung an die Folgen des Klimawandels für ein nachhaltiges Schweizer Ernährungssystem. 1. Teil: Grundsätze, Ziele und Stossrichtungen. Bundesamt für Landwirtschaft, Bundesamt für Lebensmittelsicherheit und Veterinärwesen & Bundesamt für Umwelt. Bern*.

Fontana, M.-C., Haering, B., Koch, P., Meier, B., WEiss, B., Zurbrügg, C., & Lugon, A. (2019). *Evaluation der Biodiversitätsbeiträge. Schlussbericht z.H. Bundesamt für Landwirtschaft*. Retrieved from https://www.aramis.admin.ch/Grunddaten/?ProjectID=41538

Gawith, D., & Hodge, I. (2019). Focus rural land policies on ecosystem services, not agriculture. *Nature Ecology & Evolution, 3*(8), 1136-1139. https://doi.org/10.1038/s41559-019-0934-y

Gravey, V. (2019). Finally Free to Green Agriculture Policy? UK post-Brexit Policy Developments in the Shadow of the CAP and Devolution. *EuroChoices, 18*(2), 11-16. https://doi.org/10.1111/1746-692X.12234

Gray, E., Adenäuer, L., Flaig, D., & van Tongeren, F. (2017). Evaluation of the relevance of border protection for agriculture in Switzerland. https://doi.org/10.1787/6e3dc493-en

Guarín, A., Rivera, M., Pinto-Correia, T., Guiomar, N., Šūmane, S., & Moreno-Pérez, O. M. (2020). A new typology of small farms in Europe. *Global Food Security, 26*, 100389. https://doi.org/10.1016/j.gfs.2020.100389

Guerrero, S. (2021). *Characterising agri-environmental policies*. Retrieved from https://www.oecd-ilibrary.org/content/paper/41257e3c-en

Guyomard, H., Détang-Dessendre, C., Dupraz, P., Delaby, L., Huyghe, C., Peyraud, J.-L., … Sirami, C. (2023). How the Green Architecture of the 2023–2027 Common Agricultural Policy could have been greener. *AMBIO*. https://doi.org/10.1007/s13280-023-01861-0

Hediger, W. (2006). Concepts and Definitions of Multifunctionality in Swiss Agricultural Policy and Research. *European Series on Multifunctionality, 2006 (10), S149-174.*

Herzog, F., Dreier, S., Hofer, G., Marfurt, C., Schüpbach, B., Spiess, M., & Walter, T. (2005). Effect of ecological compensation areas on floristic and breeding bird diversity in Swiss agricultural landscapes. *Agriculture, Ecosystems & Environment, 108*(3), 189-204. Retrieved from http://www.sciencedirect.com/science/article/B6T3Y-4FJD9G6-1/2/df6bd58dc2c6473559660e2375cd254d

Herzog, F., Jacot, K., Tschumi, M., & Walter, T. (2017). The Role of Pest Management in Driving Agri-environment Schemes in Switzerland. In *Environmental Pest Management* (pp. 385-403).

Herzog, F., Prasuhn, V., Spiess, E., & Richner, W. (2008). Environmental cross-compliance mitigates nitrogen and phosphorus pollution from Swiss agriculture. *Environmental Science & Policy, 11*(7), 655-668. http://dx.doi.org/10.1016/j.envsci.2008.06.003

Herzog, F., & Seidl, I. (2018). Swiss alpine summer farming: current status and future development under climate change. *The Rangeland Journal, 40*(5), 501-511. https://doi.org/10.1071/RJ18031

Hillen, J. (2019). Market Integration and Market Efficiency under Seasonal Tariff Rate Quotas. *Journal of Agricultural Economics, 70*(3), 859-873. https://doi.org/10.1111/1477-9552.12355

Hillen, J. (2021). Vertical price transmission in Swiss dairy and cheese value chains. *Agricultural and Food Economics, 9*(1), 13. https://doi.org/10.1186/s40100-021-00187-3

Hillen, J., & von Cramon-Taubadel, S. (2019). Protecting the Swiss milk market from foreign price shocks: Public border protection vs. quality differentiation. *Agribusiness, 35*(4), 516-536. https://doi.org/10.1002/agr.21602

Hirschi, C., Widmer, A., Briner, S., & Huber, R. (2013). Combining Policy Network and Model-Based Scenario Analyses: An Assessment of Future Ecosystem Goods and Services in Swiss Mountain Regions. *Ecology and Society, 18*(2). https://doi.org/10.5751/ES-05480-180242

Huber, R. (2022). *Einführung in die Schweizer Agrarpolitik*. Zürich: vdf Verlag.

Huber, R., & Finger, R. (2019). Popular initiatives increasingly stimulate agricultural policy in Switzerland. *18*(2), 38-39. https://doi.org/10.1111/1746-692x.12209

Huber, R., Flury, C., Meier, B., & Mack, G. (2017). Direktzahlungen sorgfältig aufeinander abstimmen. *Agrarforschung Schweiz, 8*(1), 26-29. https://doi.org/10.3929/ethz-b-000234152

Huber, R., Meier, B., & Flury, C. (2014). *Evaluation, Weiterentwicklung und Alternativen des SAK-Systems. Bericht zuhanden des Bundesamts für Landwirtschaft*. Retrieved from

Huber, R., Späti, K., & Finger, R. (2023). A behavioural agent-based modelling approach for the ex-ante assessment of policies supporting precision agriculture. *Ecological Economics, 212*, 107936. https://doi.org/10.1016/j.ecolecon.2023.107936

Huber, R., Zabel, A., Schleiffer, M., Vroege, W., Brändle, J. M., & Finger, R. (2021). Conservation Costs Drive Enrolment in Agglomeration Bonus Scheme. *Ecological Economics, 186*, 107064. https://doi.org/10.1016/j.ecolecon.2021.107064

Irek, J. (2022). *Characterizing Swiss NTM trade policy for agri-food products : From technical barriers to sustainability standards. Agroscope Science, 148, 2022, 1-27.* https://doi.org/10.34776/as148e

Jenny, M., Studer, J., & Bosshard, A. (2018). *Evaluation Vernetzungsprojekte*. Retrieved from Sempach:

Kampmann, D., Herzog, F., Jeanneret, P., Konold, W., Peter, M., Walter, T., … Lüscher, A. (2008). Mountain grassland biodiversity: Impact of site conditions versus management type. *Journal for Nature Conservation, 16*(1), 12-25. http://doi.org/10.1016/j.jnc.2007.04.002

Kampmann, D., Lüscher, A., Konold, W., & Herzog, F. (2012). Agri-environment scheme protects diversity of mountain grassland species. *Land Use Policy, 29*(3), 569-576. Retrieved from http://www.sciencedirect.com/science/article/pii/S0264837711001049

Kanter, D. R., Bartolini, F., Kugelberg, S., Leip, A., Oenema, O., & Uwizeye, A. (2020). Nitrogen pollution policy beyond the farm. *Nature Food, 1*(1), 27-32. https://doi.org/10.1038/s43016-019-0001-5

Kelemen, E., Megyesi, B., Matzdorf, B., Andersen, E., van Bussel, L. G. J., Dumortier, M., … Yacamán-Ochoa, C. (2023). The prospects of innovative agri-environmental contracts in the European policy context: Results from a Delphi study. *Land Use Policy, 131*, 106706. https://doi.org/10.1016/j.landusepol.2023.106706

Knop, E., Kleijn, D., Herzog, F., & Schmid, B. (2006). Effectiveness of the Swiss agri-environment scheme in promoting biodiversity. *Journal of Applied Ecology, 43*(1), 120-127. https://doi.org/10.1111/j.1365-2664.2005.01113.x

Koch, B. (2002). *Evaluation der Schweizer Agrarmarktpolitik unter besonderer Berücksichtigung von Unsicherheit. eine agrarökonomische Analyse der Märkte für Getreide, Milch, Fleisch und Eier.* ETH Zürich, Retrieved from http://hdl.handle.net/20.500.11850/145699

Kreft, C., Finger, R., & Huber, R. (2023). Action- versus results-based policy designs for agricultural climate change mitigation. *Applied Economic Perspectives and Policy, n/a*(n/a). https://doi.org/10.1002/aepp.13376

Kupper, T., Bonjour, C., & Menzi, H. (2015). Evolution of farm and manure management and their influence on ammonia emissions from agriculture in Switzerland between 1990 and 2010. *Atmospheric Environment, 103*, 215-221. https://doi.org/10.1016/j.atmosenv.2014.12.024

Lauber, S., Calabrese, C., Von Felten, S., Fischer, M., & Schulz, T. (2011). Evaluation der Sömmerungsbeitragsverordnung (SöBV) und alternativer Steuerungsinstrumente für das Sömmerungsgebiet. *ART, Ettenhausen, und WSL, Birmensdorf, 2.*

Leifeld, J., & Fuhrer, J. (2005). Greenhouse gas emissions from Swiss agriculture since 1990: implications for environmental policies to mitigate global warming. *Environmental Science & Policy, 8*(4), 410-417. https://doi.org/10.1016/j.envsci.2005.04.001

Loi, A., Esposti, R., Gentile, M., Bruni, M., Saguatti, A., Berisio, S., … Huber, M. (2016). Policy evaluation of tariff rate quotas. *Report mandated by the Swiss Federal Office of Agriculture. Bologna: Areté srl.*

Mack, G., Finger, R., Ammann, J., & El Benni, N. (2023). Modelling policies towards pesticide-free agricultural production systems. *Agricultural Systems, 207*, 103642. https://doi.org/10.1016/j.agsy.2023.103642

Mack, G., & Huber, R. (2017). On-farm compliance costs and N surplus reduction of mixed dairy farms under grassland-based feeding systems. *Agricultural Systems, 154*, 34-44. http://doi.org/10.1016/j.agsy.2017.03.003

Mack, G., & Kohler, A. (2019). Short- and Long-Run Policy Evaluation: Support for Grassland-Based Milk Production in Switzerland. *Journal of Agricultural Economics, 70*(1), 215-240. https://doi.org/10.1111/1477-9552.12284

Mack, G., Kohler, A., Heitkämper, K., & El-Benni, N. (2019). Determinants of the perceived administrative transaction costs caused by the uptake of an agri-environmental program. *Journal of Environmental Planning and Management, 62*(10), 1802-1819. https://doi.org/10.1080/09640568.2018.1515311

Mack, G., Ritzel, C., Heitkämper, K., & El Benni, N. (2021). The Effect of Administrative Burden on Farmers' Perceptions of Cross-Compliance-Based Direct Payment Policy. *Public Administration Review, n/a*(n/a). https://doi.org/10.1111/puar.13335

Mack, G., Ritzel, C., & Jan, P. (2020). Determinants for the Implementation of Action-, Result- and Multi-Actor-Oriented Agri-Environment Schemes in Switzerland. *Ecological Economics, 176*, 106715. https://doi.org/10.1016/j.ecolecon.2020.106715

Mann, S. (2003). Doing it the Swiss Way. *EuroChoices, 2*(3), 32-35. doi:10.1111/j.1746-692X.2003.tb00060.x

Mann, S. (2010). Eine Schwachstellenanalyse der Ökoqualitätsverordnung. *Agrarforschung Schweiz, 1*(1), 24-29.

Mann, S., Hunziker, M., Torregroza, L., Wartmann, F., Kienast, F., & Schüpbach, B. (2023). Landscape quality payments in Switzerland: The congruence between policy and preferences. *Journal of Policy Modeling, 45*(2), 251-265. https://doi.org/10.1016/j.jpolmod.2023.03.007

Mann, S., & Kaiser, A. (2023). Why is agricultural policy not more environmentally ambitious? Comparing failed attempts in Switzerland. *Resources, Environment and Sustainability, 11*, 100096. https://doi.org/10.1016/j.resenv.2022.100096

Mann, S., & Lanz, S. (2013). Happy Tinbergen: Switzerland's New Direct Payment System. *EuroChoices, 12*(3), 24-28. https://doi.org/10.1111/1746-692X.12036

Mann, S., & Mack, G. (2004). Wirkungsanalyse der Allgemeinen Direktzahlungen. *FAT-Schriftenreihe Nr. 64. Agroscope, Tänikon.*

Maye, D., Kirwan, J., Schmitt, E., Keech, D., & Barjolle, D. (2016). PDO as a Mechanism for Reterritorialisation and Agri-Food Governance: A Comparative Analysis of Cheese Products in the UK and Switzerland. *Agriculture, 6*(4), 54. Retrieved from https://www.mdpi.com/2077-0472/6/4/54

Meemken, E.-M., Barrett, C. B., Michelson, H. C., Qaim, M., Reardon, T., & Sellare, J. (2021). Sustainability standards in global agrifood supply chains. *Nature Food, 2*(10), 758-765.

Meier, B., Giuliani, G., & Flury, C. (2009). Flächentransfers und Agrarstrukturentwicklung bis 2007. *Agrarforschung, 16*(5), 152-157.

Meier, E., Lüscher, G., Buholzer, S., Herzog, F., Indermaur, A., Riedel, S., … Knop, E. (2021). Zustand der Biodiversität in der Schweizer Agrarlandschaft. *Agroscope Science, 111*, 1-88.

Mesnage, R., Straw, E. A., Antoniou, M. N., Benbrook, C., Brown, M. J. F., Chauzat, M.-P., … Zioga, E. (2021). Improving pesticide-use data for the EU. *Nature Ecology & Evolution, 5*(12), 1560-1560. https://doi.org/10.1038/s41559-021-01574-1

Metz, F., Lieberherr, E., Schmucki, A., & Huber, R. (2020). Policy change through negotiated agreements: The case of greening Swiss agricultural policy. *Policy Studies Journal*. https://doi.org/10.1111/psj.12417

Möhring, A., Mack, G., Zimmermann, A., Mann, S., & Ferjani, A. (2018). Evaluation Versorgungssicherheitsbeiträge. *Schlussbericht. Agroscope Science, 66*.

Möhring, A., & Mann, S. (2020). Causes and impacts of the mis-representation of agricultural policy—The case of food supply security payments in Switzerland. *Journal of Policy Modeling, 42*(2), 466-482. https://doi.org/10.1016/j.jpolmod.2020.01.002

Möhring, N., & Finger, R. (2022). Pesticide-free but not organic: adoption of a large-scale wheat production standard in Switzerland. *Food Policy, 106*, 102188.

Möhring, N., Ingold, K., Kudsk, P., Martin-Laurent, F., Niggli, U., Siegrist, M., … Finger, R. (2020). Pathways for advancing pesticide policies. *Nature Food, 1*(9), 535-540. https://doi.org/10.1038/s43016-020-00141-4

Möhring, N., Kanter, D., Aziz, T., Castro, I. B., Maggi, F., Schulte-Uebbing, L., … Leadley, P. (2023). Successful implementation of global targets to reduce nutrient and pesticide pollution requires suitable indicators. *Nature Ecology & Evolution, 7*(10), 1556-1559. https://doi.org/10.1038/s41559-023-02120-x

Navarro, A., & López-Bao, J. V. (2018). Towards a greener Common Agricultural Policy. *Nature Ecology & Evolution, 2*(12), 1830-1833. https://doi.org/10.1038/s41559-018-0724-y

Necpalova, M., Lee, J., Skinner, C., Büchi, L., Wittwer, R., Gattinger, A., … Six, J. (2018). Potentials to mitigate greenhouse gas emissions from Swiss agriculture. *Agriculture, Ecosystems & Environment, 265*, 84-102. https://doi.org/10.1016/j.agee.2018.05.013

Nemecek, T., Huguenin-Elie, O., Dubois, D., Gaillard, G., Schaller, B., & Chervet, A. (2011). Life cycle assessment of Swiss farming systems: II. Extensive and intensive production. *Agricultural Systems, 104*(3), 233-245. https://doi.org/10.1016/j.agsy.2010.07.007

Nitsch, H., & Osterburg, B. (2005). *Cross Compliance (CC) in der EU und Ökologischer Leistungsnachweis (ÖLN) in der Schweiz: eine vergleichende Analyse*. Retrieved from https://www.aramis.admin.ch/Grunddaten/?ProjectID=18415

Obrist, R., Moschitz, H., Home, R., & (2015). Das landwirtschaftliche Wissenssystem in der Schweiz neu gestalten. *Agrarforschung Schweiz, 6*(5), 218-223.

OECD. (2015). *OECD Review of Agricultural Policies: Switzerland 2015*: OECD Publishing.

OECD. (2022). *Agricultural support (indicator). doi: 10.1787/6ea85c58-en (Accessed on 08 November 2022).*

Pe'er, G., Bonn, A., Bruelheide, H., Dieker, P., Eisenhauer, N., Feindt, P. H., … Lakner, S. (2020). Action needed for the EU Common Agricultural Policy to address sustainability challenges. *People and Nature, 2*(2), 305-316. https://doi.org/10.1002/pan3.10080

Pe'er, G., Dicks, L. V., Visconti, P., Arlettaz, R., Báldi, A., Benton, T. G., … Scott, A. V. (2014). EU agricultural reform fails on biodiversity. *Science, 344*(6188), 1090-1092. https://doi.org/10.1126/science.1253425

Pe'er, G., Zinngrebe, Y., Moreira, F., Sirami, C., Schindler, S., Müller, R., … Lakner, S. (2019). A greener path for the EU Common Agricultural Policy. *Science, 365*(6452), 449-451. https://doi.org/10.1126/science.aax3146 %J Science

Poppe, K., & Koutstaal, H. (2020). Eco-Schemes and Private Sustainability Initiatives: Creating Synergies. *EuroChoices, 19*(1), 36-40.

Reutimann, J., Ehrler, A., & Schäppi, B. (2022). *Aktualisierung Stoffflussanalyse Stickstoff für das Jahr 2018. Schlussbericht zuhanden des Bundesamts für Landwirtschaft. Bern.* Retrieved from

Rieder, P., Buchli, S., & Kopainsky, B. (2004). *Erfüllung des Verfassungsauftrags durch die Landwirtschaft unter besonderer Berücksichtigung ihres Beitrags zur dezentralen Besiedlung*. Retrieved from Zürich:

Ritzel, C., Mack, G., Portmann, M., Heitkämper, K., & El Benni, N. (2020). Empirical evidence on factors influencing farmers' administrative burden: A structural equation modeling approach. *PLoS ONE, 15*(10), e0241075. https://doi.org/10.1371/journal.pone.0241075

Roederer-Rynning, C., & Matthews, A. (2019). What common agricultural policy after Brexit? *Politics and Governance, 7*(3), 40-50.

Schader, C., Lampkin, N., Christie, M., Nemecek, T., Gaillard, G., & Stolze, M. (2013). Evaluation of cost-effectiveness of organic farming support as an agri-environmental measure at Swiss agricultural sector level. *Land Use Policy, 31*(0), 196-208. https://doi.org/10.1016/j.landusepol.2012.06.014

Schaub, S., Huber, R., & Finger, R. (2020). Tracking societal concerns on pesticides – A Google Trends analysis. *Environmental Research Letters*. Retrieved from http://iopscience.iop.org/10.1088/1748-9326/ab9af5

Schebesta, H., & Candel, J. J. L. (2020). Game-changing potential of the EU's Farm to Fork Strategy. *Nature Food, 1*(10), 586-588. https://doi.org/10.1038/s43016-020-00166-9

Schirpke, U., Tasser, E., Leitinger, G., & Tappeiner, U. (2022). Using the Ecosystem Services Concept to Assess Transformation of Agricultural Landscapes in the European Alps. *Land, 11*(1), 49. Retrieved from https://www.mdpi.com/2073-445X/11/1/49

Schleiffer, M., Landert, J., & Moschitz, H. (2022). Assessing public organic food procurement: the case of Zurich (CH). *Organic Agriculture, 12*(3), 461-474. https://doi.org/10.1007/s13165-022-00402-5

Schmid, H. P., & Lehmann, B. (2000). Switzerland: agrienvironmental policy outside the European Union In H. Buller, G. A. Wilson, & A. Höll (Eds.), *Agri-environmental Policy in the European Union*. London: Routledge.

Schmidt, A., Mack, G., Mann, S., & Six, J. (2021). Reduction of nitrogen pollution in agriculture through nitrogen surplus quotas: an analysis of individual marginal abatement cost and different quota allocation schemes using an agent-based model. *Journal of Environmental Planning and Management, 64*(8), 1375-1391. https://doi.org/10.1080/09640568.2020.1823344

Schmidt, A., Mack, G., Möhring, A., Mann, S., & El Benni, N. (2019). Stricter cross-compliance standards in Switzerland: Economic and environmental impacts at farm- and sector-level. *Agricultural Systems, 176*, 102664. https://doi.org/10.1016/j.agsy.2019.102664

Schmidt, A., Necpalova, M., Mack, G., Möhring, A., & Six, J. (2021). A food tax only minimally reduces the N surplus of Swiss agriculture. *Agricultural Systems, 194*, 103271. https://doi.org/10.1016/j.agsy.2021.103271

Schmidt, A., Necpalova, M., Zimmermann, A., Mann, S., Six, J., & Mack, G. (2017). Direct and Indirect Economic Incentives to Mitigate Nitrogen Surpluses: A Sensitivity Analysis. *Journal of Artificial Societies and Social Simulation, 20*(4), 7. https://doi.org/10.18564/jasss.3477

Schulz, T., Lauber, S., & Herzog, F. (2018). Summer Farms in Switzerland: Profitability and Public Financial Support. *Mountain Research and Development, 38*(1), 14-23, 10. https://doi.org/10.1659/MRD-JOURNAL-D-16-00118.1

Spörri, M., El Benni, N., Mack, G., & Finger, R. (2023). Spatio-temporal dynamics of grassland use intensity in Switzerland. *Regional Environmental Change, 23*(1), 23. https://doi.org/10.1007/s10113-022-02023-w

Spycher, S., Mangold, S., Doppler, T., Junghans, M., Wittmer, I., Stamm, C., & Singer, H. (2018). Pesticide Risks in Small Streams—How to Get as Close as Possible to the Stress Imposed on Aquatic Organisms. *Environmental Science & Technology, 52*(8), 4526-4535. https://doi.org/10.1021/acs.est.8b00077

Steiger, U., Lüthi, S., Schmitt, H.-M., & Schüpbach, W. (2016a). *Evaluation Landschaftsqualitätsbeiträge. Schlussbericht z.H. Bundesamt für Landwirtschaft*.

Steiger, U., Lüthi, S., Schmitt, H.-M., & Schüpbach, W. (2016b). *Evaluation Landschaftsqualitätsbeiträge. Schlussbericht zuhanden des Bundesamts für Landwirtschaft*. Retrieved from Zürich, Rapperswil, Mollis:

Suter, S., Mattmann, M., Bachmann, T., Hänni, E., Hochuli, A., & Huber, M. (2016). Beitrag der Landwirtschaft und der Agrarpolitik zur Vitalität und Attraktivität des ländlichen Raums. *Bern/Zollikofen: Ecoplan/Berner Fachhochschule, Hochschule für Agrar-, Forst-und Lebensmittelwissenschaften HAFL*.

Swinnen, J. F. (2018). *The political economy of agricultural and food policies*: Springer.

Tauger, M. B. (2020). *Agriculture in world history*: Routledge.

Tschumi, M., Albrecht, M., Bärtschi, C., Collatz, J., Entling, M. H., & Jacot, K. (2016). Perennial, species-rich wildflower strips enhance pest control and crop yield. *Agriculture, Ecosystems & Environment, 220*, 97-103. https://doi.org/10.1016/j.agee.2016.01.001

Tschumi, M., Albrecht, M., Entling, M. H., & Jacot, K. (2015). High effectiveness of tailored flower strips in reducing pests and crop plant damage. *Proceedings of the Royal Society B: Biological Sciences, 282*(1814), 20151369. https://doi.org/10.1098/rspb.2015.1369

Wey, C., & Gösser, N. (2019). *Eine Bewertung der Rolle des Grenzschutzes auf die landwirtschaftlichen Betriebe in der Schweiz und ihre vorgelagerten Industrien. Eine Studie im Auftrag des Bundesamts für Landwirtschaft, Bern, Schweiz*. Retrieved from https://www.blw.admin.ch/blw/de/home/international/agrarmaerkte-und-agrarhandel/studien-grenzschutz.html

Wuepper, D., & Huber, R. (2022). Comparing effectiveness and return on investment of action- and results-based agri-environmental payments in Switzerland. *American Journal of Agricultural Economics, n/a*(n/a). https://doi.org/10.1111/ajae.12284

Wunder, S., Börner, J., Ezzine-de-Blas, D., Feder, S., & Pagiola, S. (2020). Payments for Environmental Services: Past Performance and Pending Potentials. *Annual Review of Resource Economics, 12*(1), 209-234. https://doi.org/10.1146/annurev-resource-100518-094206

Wunder, S., Brouwer, R., Engel, S., Ezzine-de-Blas, D., Muradian, R., Pascual, U., & Pinto, R. (2018). From principles to practice in paying for nature's services. *Nature Sustainability, 1*(3), 145-150. https://doi.org/10.1038/s41893-018-0036-x

Zellweger-Fischer, J., Kéry, M., & Pasinelli, G. (2011). Population trends of brown hares in Switzerland: The role of land-use and ecological compensation areas. *Biological Conservation, 144*(5), 1364-1373. https://doi.org/10.1016/j.biocon.2010.11.021

Zimmermann, A., Baumgartner, D., Nemecek, T., & Gaillard, G. (2011). Are public payments for organic farming cost-effective? Combining a decision-support model with LCA. *The International Journal of Life Cycle Assessment, 16*(6), 548-560. https://doi.org/10.1007/s11367-011-0286-6

Zimmert, F., & Zorn, A. (2022). Direct payments and on-farm employment: Evidence from a spatial regression discontinuity design. *Q Open*. https://doi.org/10.1093/qopen/qoac024

Zingg, S., Grenz, J., & Humbert, J.-Y. (2018). Landscape-scale effects of land use intensity on birds and butterflies. *Agriculture, Ecosystems & Environment, 267*, 119-128. https://doi.org/https://doi.org/10.1016/j.agee.2018.08.014

Zingg, S., Ritschard, E., Arlettaz, R., & Humbert, J.-Y. (2019). Increasing the proportion and quality of land under agri-environment schemes promotes birds and butterflies at the landscape scale. *Biological Conservation, 231*, 39-48. https://doi.org/10.1016/j.biocon.2018.12.022

Zorn, A., & Zimmert, F. (2022). Structural change in the dairy sector: exit from farming and farm type change. *Agricultural and Food Economics, 10*(1), 7. https://doi.org/10.1186/s40100-022-00212-z

BAE
Bio-based and Applied Economics

AIEAA
ASSOCIAZIONE ITALIANA DI ECONOMIA AGRARIA E APPLICATA

OPEN ACCESS

Citation: Pagliacci, F., & Zavalloni, M. (2024). The political economy determinants of agri-environmental funds in the European Rural Development Programmes. *Bio-based and Applied Economics* 13(2): 147-160. doi: 10.36253/bae-13482

Received: August 30, 2022
Accepted: September 29, 2023
Published: July 25, 2024

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Editor: Fabio Santeramo; Silvia Coderoni

ORCID
FP: 0000-0002-3667-7115
MZ: 0000-0002-6291-7653

The political economy determinants of agri-environmental funds in the European Rural Development Programmes

Francesco Pagliacci[1], Matteo Zavalloni[2,*]

[1] *Dipartimento Territorio e Sistemi Agro-Forestali (TESAF), Università di Padova, Italy*
[2] *Dipartimento di Economia, Società, Politica (DESP), Università degli Studi di Urbino Carlo Bo, Italy*
*Corresponding author. E-mail: matteo.zavalloni@uniurb.it

Abstract. In recent years, agricultural policies have expanded their scope to include funding for the promotion of environmental sustainability in agriculture. However, these policies have been often overlooked in the political economy literature. This article aims to investigate the factors influencing the allocation of funds towards environmental goals in the Rural Development Programmes of the European Union Common Agricultural Policy. The main findings of this study indicate a positive correlation between GDP per capita and the allocation of the environmental budget. Conversely, delegating the management of these programmes to sub-national polities has a negative impact on the budget allocation. Therefore, it seems that maintaining some central control over the budget allocation might favour the environmental sustainability of the agricultural sector.

Keywords: EU Rural Development Policy, political economy, agri-environmental schemes, environmental federalism.
JEL Codes: D72, O13, Q18.

1. INTRODUCTION

Agriculture has been historically the subject of pervasive policy interventions, even though their nature has been extensively developed over time. The general pattern is that, with economic development, interventions tend to switch from dis-incentivization toward subsidization of agricultural activities (Anderson et al., 2013). Even within high income economies the support to agriculture has substantially evolved over time, from price support, toward coupled and ultimately non-coupled subsidies (Anderson et al., 2013). Especially in high income economies, since the 1980s, the scope of government interventions has broadened from a support to production to larger shares of funds allocated to e.g. R&D (Swinnen et al., 2000), infrastructures development (OECD, 2020) and the environmental goals (Baylis et al., 2008). For example, in the European Union since the 2000s, funds of the Common Agricultural Policy (CAP) have been allocated, through the Rural Development Programmes (RDPs), to agri-environmental schemes, aimed at incentivizing the provision of environmental public goods (Matthews, 2013).

To explain the existence and persistence of agricultural policies, the literature has relied on the lens of political economy (Swinnen, 1994). A number of determinants have been empirically analysed, among the others: electoral incentives (Fałkowski and Olper, 2014), personal preferences of the legislators (Bellemare and Carnes, 2015), lobbying and institutional settings (Olper et al., 2014). However, the great bulk of the literature has focused on the determinants of the *extensive* margins of agricultural policies, i.e., to what extent the agricultural sector is affected by government interventions (Anderson et al., 2013). Surprisingly little has been said on in the *intensive* margins of agricultural policies, i.e. what determines the allocation of funds, within agricultural policies, for objectives that are beyond production or maintenance of agriculture.

The objective of this article is to assess the political economy determinants of the allocation of agricultural policy funds toward environmental goals. Our focus is on the European RDPs. The decisions on RDP fund allocations are set within a common, EU-level, framework (e.g., common priorities), but are eventually delegated to national or subnational authorities, according to the principle of vertical subsidiarity. Thus, they provide an interesting example for the issue here at stake. We address five main sets of explicatory variables: the societal demand for a greater environmental quality; the importance of the agricultural sector in the economy, which reflects into its bargaining power; the political characteristics –the ideology of the government coalitions in charge; the agri-environmental conditions of the area; and whether the RDP is managed at the national or subnational level (i.e., issue of decentralization). Using a fractional regression model, we find that the most robust determinants of environmental budget allocations are GDP per capita (positively correlated), population density and management decentralization (both negatively correlated).

The main value of the article is to complement the literature on the political economy of agricultural policies by unveiling the determinants of funds for agri-environmental goals, a topic largely ignored so far (Fredriksson and Svensson, 2003), even though on the rise (Mamun et al., 2021). Indeed, several articles focus on the determinants of *expenditures* on the agri-environmental schemes of the European RDPs (Bertoni and Olper, 2012; Camaioni et al., 2019, 2016, 2013; Glebe and Salhofer, 2007; Zasada et al., 2018), or of similar measures (Hackl et al., 2007). While expenditures and budgets are obviously connected, looking at the former adds the noise of the specific design of the measures and of the farmers uptake, and cannot be fully interpreted as a government choice (Glebe and Salhofer, 2007).

At the same time, this article also speaks to the more general literature on the relationship between institutions and environmental quality, which has not deepened the topic on agricultural policies (Dasgupta and De Cian, 2018). One of the few exceptions is the analysis by Fredriksson and Svensson (2003), who investigate the link between political instability and the stringency of environmental regulation (hence, not subsidy) faced by the agricultural sector.

Finally, we also contribute to the literature on effect of environmental policies decentralization (Droste et al., 2018; Fredriksson and Wollscheid, 2014; Sigman, 2014). The framework of the RDP implementations, that are managed by both national and subnational authorities, enables to give insights also on the consequence of policy decentralization, an issue that has been seldom investigated with respect to agricultural policies (Bareille and Zavalloni, 2020).

The results provide several policy implications. Despite the paucity of the literature on the issues, the environmental impact of the agricultural sector is a major concern (Crippa et al., 2021), and understanding the drivers of policies addressing it seems of paramount importance. Finally, decentralization of agricultural policies is often debated for the CAP reforms and our results can feed the debate revolving on it (*COM(2018) 392 final*, 2018). The remainder of the paper is structured as follows. Section 2 provides a policy background focusing on the environmental goals in agriculture and on the EU 2014-2020 programming period of the CAP. Section 3 describes selected data and implemented methods. Section 4 shows and discusses the main results. Section 5 concludes and provides some policy recommendations.

2. BACKGROUND: ENVIRONMENTAL GOALS IN AGRICULTURAL POLICIES AND IN THE EU RURAL DEVELOPMENT PROGRAMMES

Environmental goals attached to agricultural subsidies are a longstanding, albeit minor, presence. In the USA, a first example is the 1936 Soil Conservation Act, aimed at incentivizing soil conservation practices (Cain and Lovejoy, 2004). Only since the 1980s, however, in OECD countries the share of budget linked to environmentally friendly practices has substantially increased (Guerrero, 2021). Indeed in 1985 environmental protection became the main (nominal) rationale for the imple-

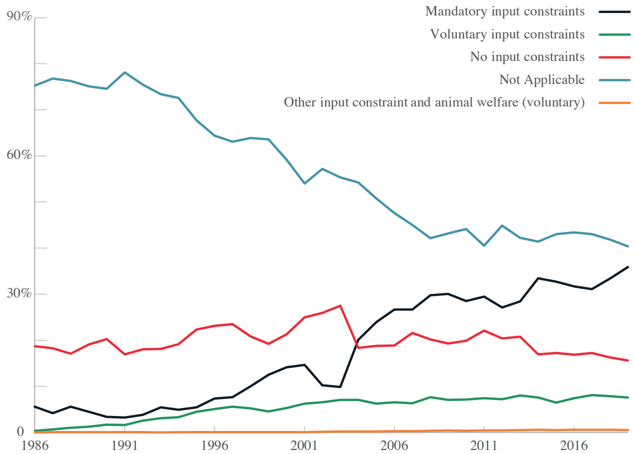


Figure 1. Share of subsidy type on the total Producer Support Estimate for a set of countries (OECD and others). Own elaboration on data from OECD (2020), downloadable at https://www.oecd.org/agriculture/topics/agricultural-policy-monitoring-and-evaluation/. For technical explanation of the variables, we refer to OECD (2016).

mentation of the USA Conservation Reserve Programme, subsidising practices aimed at e.g. improving environmental quality or providing wildlife habitat (Hellerstein, 2017). Similarly, in 1985 an EU regulation allowed member states to design incentives for farmers implementing environmentally friendly practices, even though the uptake of this possibility was rather limited (Matthews, 2013). For a set of countries (OECD and others), Figure 1 shows that most of the budget toward environmental goals is linked to general support to agriculture conditional on some forms of input constraint -*mandatory input constraints*, in Figure 1. Voluntary measures – *voluntary environmental input constraints*, in Figure 1 – such as the agri-environmental schemes have also increased over time, even though they remain limited to about 6-7% of the total support (Guerrero, 2021).

In the EU, voluntary agri-environmental measures are currently implemented within the RDPs. RDPs represent the so-called Pillar 2 of the CAP. They were first formulated in the Agenda 2000 reform, as part of a strategy to move away from coupled support and broaden the scope of the CAP (Matthews et al., 2017) and they are currently supported by the European Agricultural Fund for Rural Development (EAFRD) of the EU. Since the Agenda 2000 reform, four programming periods have taken place: 2000-2006, 2007-2013, 2014-2020, 2021-2027. A comprehensive overview of the CAP and its environmental goals is out of the scope of this paper, and we refer to e.g. Matthews (2013) for a detailed description of the topic.

The current version of the Rural Development Policy is the 2021-2027 one, which in fact has only started in 2023, i.e., with a two-year delay. It followed extensive negotiations between the European Parliament, the Council of the EU and the European Commission for the approval of the Multiannual Financial Framework of the EU (as a consequence of both Brexit process and the outbreak of the Covid-19 pandemics). Thus, due to the lack of data on the current programming period, our analysis focuses on the 2014-2020 programming period, when the RDPs were legislatively based on the Regulation (EU) No 1305/2013 of the European Parliament and of the Council, which provided the guidelines for their formulations and structure. Even though the general framework was set at the EU level and plans were approved by the EC, national authorities had some degree of freedom in implementing them (eventually increased in the current 2021-2027 programming period). First, following the vertical subsidiarity principle, member states could delegate the management of the RDPs to subnational authorities (Beckmann et al., 2009). During the 2014-2020 programming period, 20 EU Member States maintained a nation-wide implementation, while the remaining countries opted for a subnational implementation. On the one hand, Germany, Belgium, Finland, Portugal, and the UK opted for the NUTS-1 level implementation (considering either single NUTS-1 regions, e.g., the *Länder* in Germany or groups of them, as in the case of the UK). On the other, France, Italy, and Spain opted for the NUTS-2 level implementation (e.g., the *Régions* in France, the *Regioni* in Italy, and the *Comunidades Autónomas* in Spain). Second, the managing authorities – either at the national or the subnational level – chose their own allocation of funds, with some constraints, prioritising specific goals among the existing ones.

According to article 5 of the Regulation No 1305/2013, the RDP budgets, funded by the EAFRD, must be shared among, centrally determined, 6 priorities, or goals: (1) fostering knowledge transfer and innovation in agriculture, (2) enhancing farm viability and competitiveness, (3) promoting food chain organisation, (4) restoring, preserving and enhancing ecosystems related to agriculture and forestry, (5) promoting resource efficiency and supporting the shift towards a low carbon and climate resilient economy, (6) promoting social inclusion. At the same time, EAFRD budget was allocated to a set of measures, i.e., specific areas of interventions, aimed at achieving the aforementioned goals (Table 1).

Within the current framework and according to the classification provided in Table 1, environmental measures are granted a specific attention. According to article 59 of the Regulation No 1305/2013, at least 30 % of the total EAFRD contribution to each RDP shall be reserved

Table 1. Description of measures and related articles in the Regulation No 1305/2013.

Articles	Short description	RDP codes
14	Knowledge transfer and information actions	M01
15	Advisory services, farm management and farm relief services	M02
16	Quality schemes for agricultural products, and foodstuffs	M03
17	Investments in physical assets	M04
18	Restoring agricultural production potential damaged by natural disasters and catastrophic events and introduction of appropriate prevention actions	M05
19	Farm and business development	M06
20	Basic services and village renewal in rural areas	M07
21-26	Investments in forest area development and improvement of the viability of forests	M08
27	Setting -up of producer groups and organisations	M09
28	Agri-environment-climate	M10
29	Organic farming	M11
30	Natura 2000 and Water Framework Directive payments	M12
31-32	Payments to areas facing natural or other specific constraints	M13
33	Animal welfare	M14
34	Forest-environmental and climate services and forest conservation	M15
35	Co-operation	M16
36-39	Risk management	M17
40	Financing of complementary national direct payments for Croatia	M18
42-44	Leader	M19

for the following measures: M04 (only considering environment and climate related investments), M08, M10, M11, M12 (except for Water Framework Directive related payments), M13 and M15. This is to achieve specific environmental goals in the EU.

3. DATA AND METHODS

3.1. Empirical model and data

The goal of this article is to assess the determinants behind the decision to allocate funds to environmental goals in the RDPs of the CAP. The shape and type of policies result from the interactions of several elements. Similarly to other analyses (e.g. Bertoni and Olper, 2012; Fredriksson and Svensson, 2003), we argue that the resulting share of budget allocated to environmental goals is determined by the interaction among five main factors: i) the societal demand for higher environmental quality, ii) the bargaining power of the agricultural sector, iii) the political environment, iv) the environmental conditions of the area, v) the polity level that manages the funds. Our expectation is that higher demand for environmental quality will be translated into relatively larger budget for environmental goals. At the same time, low environmental quality will also call for larger budget for environmental goals. However, while the funds we are investigating are targeting agriculture, the sector might prefer support to investments and efficiency, rather than sustainability goals, and hence greater bargaining power would result in lower budget for environmental goals. The political environment builds upon those two blocks. Party ideology and the composition of the government might filter the general preferences of the public. Moreover, decentralization of agri-environmental policies, while might result in better targeting of local public goods, could end up in free-riding behaviour due to spillover effects.

In the next paragraph, we describe the dependent and the explanatory variables that we use to proxy the aforementioned elements. Given the structure of the RDP managing authorities, the analysis is grounded on a territorial basis. Indeed, our units of analysis are the polities covered by each RDP managing authority, either at national or sub-national level. For the current analysis, we consider 100 RDPs and the related polities, excluding from the full set: i) the French DOM (namely, Guadeloupe, Guyane, La Réunion, Martinique and Mayotte) due to data availability, ii) the UK RDPs, for the difficulties to account for the functioning of the local (i.e., subnational) polities in that country, and iii) the national level RDPs, when the lower tiers are the main managing authorities (i.e., in the case of France, Italy, Spain).

The dependent variable is represented by the share of the RDP budget allocated to environmental measures in year 2014 (i.e., considering the first budget allocation). To operationalize the preferences for environmental goals we address the constraint set by article 59 of the Regulation No 1305/2013, in terms of both key measures and minimum budget allocation (see Section 2). We define our dependent variable, *M-environment* as the ratio between the RDP funds for environmental goals (i.e., budget allocated to measure 4, measure 8, measure 10, measure 11, measure 12, measure 13, and measure 15) that go beyond the minimum level fixed by the EU Regulation and its complementary. For example, imagine the RDP budget is 100€, and budget allocated to environmental goals is 37€. Our dependent variable is given by 7/70.

As robustness check, we also run two additional models. In the first one, we define the dependent variable as the share of the budget (year 2014) allocated to priorities (4) "restoring, preserving and enhancing ecosystems related to agriculture and forestry" and (5) "promoting resource efficiency and supporting the shift towards a low carbon and climate resilient economy" (*P-environment*); in the second one, we define the dependent variable as the share of the budget (year 2014) allocated to agri-environmental schemes only, i.e. to measure 10 (*M10*).

Figure 2 shows the rather uneven allocation of *M-environment*, *P-environment*, and *M-10* at the programming level across the EU. Data on the RDP budget allocations have been collected from the European Commission website (https://cohesiondata.ec.europa.eu/) and in all cases we considered the total financing, i.e., including both the EU EAFRD funds and the national co-financing. In particular, Table 2 returns the main descriptive statistics for the alternative specifications of the dependent variables.

We now turn to the set of explicatory variables. When considering them, the first dimension we address is the demand for environmental quality. Following previous research (e.g. Franzen and Vogl, 2013), we take into account GDP per capita and population density as a proxy for the societal demand for environmental quality. The large literature on the environmental Kuznets curve indicates that, after a certain threshold, income is a key driver of environmental quality and policy implementation (Dasgupta et al., 2002; Dinda, 2004; López and and Mitra, 2000; Maddison, 2006). Moreover, we use population density as a proxy for the degree or urbanization, which is also expected to be positively correlated to higher environmental quality, and hence higher share of budget allocated to environmental goals (e.g. Franzen and Vogl, 2013).

The second element is the economic relevance of the agricultural sector. A larger magnitude of the agricultural sector might turn into a larger bargaining power of the sector itself, which, we argue, eventually turn into a reduction of the support to environmental measures in the RDP (Fredriksson and Svensson, 2003). However, following Olson (1971), even the counterargument can be made: the larger the sector, the more is difficult to coordinate and hence the lower the bargaining power. To have proxies for the bargaining power of the agricultural sector, we rely on three indicators: share of utilised agricultural area with respect to the total area of the relevant polity, number of farmers per million inhabitants and share of Gross Value Added of agriculture out of the total Gross Value Added.

As a third group of variables, politics aspects are considered. In terms of politics, first, we consider the ideology of the government in charge. Several papers find that ideology plays a role in the level of protection and support to agriculture (Klomp and Haan, 2013; Olp-

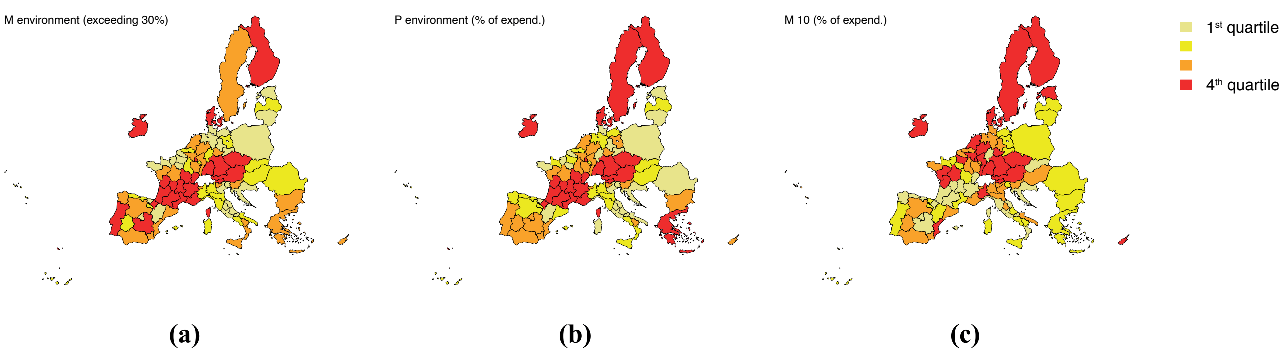


Figure 2. Allocation of environmental budget across the EU in 2014: a) M-environment, b) p-environment, and c) M-10. Source: authors' elaboration.

Table 2. List and description of the variables included in the models, by type.

	Name	Meaning	Year	Specification	Source	Mean (Std. Dev.)
Dependent variables	M-environment	Ratio of the share of the total RDP budget allocated to measure 4, measure 8, measure 10, measure 11, measure 12, measure 13, and measure 15 exceeding minimum (30%) over the total range.	2014	Share	cohesiondata.ec.europa.eu	0.27 (0.18)
	P-environment	Share of the total RDP budget allocated to priority 4, and priority 5	2014	Share	cohesiondata.ec.europa.eu	0.52 (0.12)
	M10	Share of the total RDP budget allocated to measure 10	2014	Share	cohesiondata.ec.europa.eu	0.15 (0.08)
Environmental demand	Density	Population density (thousand inhab. per square km)	avg. 2010-2014	continuous (1000 inhab.)	Eurostat - Population density	0.17 (0.19)
	GDP	Per capita income (in thousand €)	avg. 2010-2014	continuous (1000€)	Eurostat - GDP at current market prices by NUTS 2 regions	25.71 (7.86)
Bargaining power of agriculture	UAA_share	Utilised Agricultural Area (UAA) out of total land area	2013	share	Eurostat – Farm Structure Survey	0.41 (0.15)
	Farm per mill inhab	Number of farms per million inhab.	2013	continuous	Eurostat – Farm Structure Survey	19.92 (22.81)
	GVA_share	% of Agricultural Gross Value Added out of total Gross Value Added	2013	%	ARDECO database	2.85 (1.95)
Politics	Parties	Number of parties in the cabinet that was in charge at the date of approvation of the RDP	-	continuous	Authors' elaboration on Döring and Manow, (2020) Schakel and Massetti, (2018)	1.90 (1.00)
	Left_right	Average position of the cabinet in terms of its overall ideological stance (from left to right), by considering the position of each party in the coalitions (weighted by the number of their seats)	-	continuous (0 = Extreme left to 10 = Extreme right)	Authors' elaboration on Döring and Manow (2020), Schakel and Massetti (2018), Polk et al. (2017)	4.30 (1.70)
Agri-environmental conditions	N_sur_kg_ha	Average Nitrogen surplus (kg per ha), based on 16 Nitrogen surplus estimates	avg. 2010-2014	continuous	Batoo et al. (2022)	35.35 (18.15)
	Animals_ab	Thousand cows and live swines per thousand inhab.	avg. 2010-2014	continuous	Eurostat - Animal populations by NUTS 2 regions	0.57 (0.67)
	HNV	Share of high nature value (HNV) farmland out of the total area	2012	%	Authors' elaboration on European Environment Agency (EEA) data on the basis of the Corine Land Cover (CLC) accounting layers	18.76 (14.06)

(Continued)

Table 2. (Continued).

	Name	Meaning	Year	Specification	Source	Mean (Std. Dev.)
	Erosion moderate-severe	Share of agricultural areas, forest and semi natural areas under moderate or severe level of erosion, out of the total agricultural areas, forest and semi natural areas	2010	%	Eurostat - Estimated soil erosion by water, by erosion level, land cover and NUTS 3 regions (source: JRC)	17.19 (15.88)
NUTS	Nuts	RDP being managed at the sub-national level	-	Dummy	authors' elaboration	
Control variables	Pop	Total resident population	avg. 2010-2014	Continuous (million inhab.)	Eurostat - Population	4.33 (5.23)
	EEC	RDP belonging to an Eastern Europe Country	-	Dummy	authors' elaboration	

er, 2007) as well as for the level of environmental protection (Pacca et al., 2020). Following Klomp and Haan (2013), we address the ideology of the whole government cabinet (rather than simply the government head) by computing the average position of the cabinet in terms of its overall ideological stance (from left to right). Polk et al. (2017) computed ideological stance of EU parties, by assigning each of them a position on a scale from 0 (extreme left) to 10 (extreme right). Parties on the economic left wanted government to play an active role in the economy, while those on the economic right emphasized a reduced economic role for government: privatization, lower taxes, less regulation, less government spending, and a leaner welfare state. For the sake of our analysis, and as a reference point, we take the average score for the whole cabinets that were in charge of the relevant polity in the period up to the approval of the first RDP version, i.e., in most of the cases year 2014. Note that regional politics might be more complex than the national one, as regional parties are often a key player in local elections and hence governments and the local institutional architectures exhibit a great degree of heterogeneity across EU Member States (Schakel, 2013; Schakel and Massetti, 2018). Second, we also consider the number of parties that compose the government coalitions. This has been considered to affect state expenditures (Perotti and Kontopoulos, 2002) and protection to agriculture (Beghin and Kherallah, 1994).

The fourth element we address is the agri-environmental conditions of the relevant polities to which the RDPs refer. Agri-environmental measures are aimed at reorienting the sector toward more environmentally friendly practices, thus the lower the agri-environmental quality of the area, the higher the agri-environmental funds should be (Bertoni and Olper, 2012). As a proxy for environmental quality, we use four indicators: average Nitrogen surplus, number of animals (cows and live swine) per thousand inhabitants, share of high nature value (HNV) farmland out of the total area, share of agricultural areas, forest and semi natural areas under moderate or severe level of erosion. All of them are expected to be negatively correlated to environmental quality, but the share of HNV farmland.

Lastly, we address whether the RDP was managed at the national level, or if its implementation was delegated to lower tiers. We consider such an element because it is a structural characteristic of (some) RDPs, which in fact has been usually disregarded by the political economy literature of agricultural policies (as they are mostly set at the national level). However, the variation in the polity level decision making, within the same policy framework, enables to explore the effect of decentralization on (agri-) environmental policies and hence to add results to the increasing literature on environmental policy decentralization (Fredriksson and Wollscheid, 2014) and more in general on the environmental federalism (Shobe, 2020).

In addition to the previous explanatory variables, in any of the selected models we also add two variables to control for population size and Eastern European Countries (EEC). Population size is crucial to disentangle the effect of decentralization, holding the demographic size of the polity constant. The inclusion of a geographical dummy for EEC addresses the 20th-century historical differences across Europe. The list of the variables and their sources is listed in Table 2.

3.2. Econometric strategy

In the framework of the CAP, different polities manage different budget size. To control for it, we focus on the relative share of the total budget for environmental goals, rather than on its absolute value. However, fractional dependent variables – as the one under consideration here – pose some methodological challenges.

The first challenge is related to the functional form of the model (Ramalho et al., 2011). Firstly, fractional dependent data (as in this case) are bounded only within the [0, 1] interval, whereas standard econometrics generally assumes normally distributed dependent variables (Ronning, 1990). Secondly, a "negative bias" (Aitchison, 1986, p. 53) affects them, as fractional dependent variables add up to one. Even in the case of more than two categories, there will be always at least one pair of negatively correlated shares. Due to these specific properties, conventional regression models – which simply ignore the bounded nature of the dependent variable and assume a linear conditional mean model for it – should be avoided. Some scholars opted for assuming the logistic relationship, preferring to estimate by least squares the log-odds ratio model. However, this empirical strategy has some important drawbacks (see Ramalho et al., 2011 for details).

For the sake of this analysis, we adopt the fractional regression models, as originally modelled by Papke and Wooldridge (1996). Following their approach, the simplest solution for dealing with fractional response variables only requires the assumption of a functional form for y that imposes the desired constraints on the conditional mean of the dependent variable, i.e. $E(y|x) = G(x\theta)$, where G(·) is a known nonlinear function satisfying $0 \leq G(\cdot) \leq 1$. Papke and Wooldridge (1996) suggested as possible specifications for G(·) any cumulative distribution function. Among alternative choices, the logistic function is considered as an obvious choice, hence: $E(y|x) = \frac{e^{x\theta}}{1+e^{x\theta}}$. As suggested by Papke and Wooldridge (1996), this function may be consistently estimated by using the robust quasi-maximum likelihood (QML) method, which is based on the Bernoulli log-likelihood function (see Ramalho et al., 2011 for deeper details).

With regard to the empirical strategy, we estimate – for each of the dependent variables, i.e., *M-environment*, *P-environment* and *M10*, – six alternative models, as it follows:

$$\mathbf{Y} = \boldsymbol{\beta}_d\mathbf{D} + \boldsymbol{\beta}_a\mathbf{A} + \boldsymbol{\beta}_p\mathbf{P} + \boldsymbol{\beta}_e\mathbf{E} + \boldsymbol{\beta}_r\mathbf{R} + \boldsymbol{\beta}_c\mathbf{C} + \boldsymbol{\varepsilon} \quad (1)$$

$$\mathbf{Y} = \boldsymbol{\beta}_d\mathbf{D} + \boldsymbol{\beta}_c\mathbf{C} + \boldsymbol{\varepsilon} \quad (2)$$

$$\mathbf{Y} = \boldsymbol{\beta}_a\mathbf{A} + \boldsymbol{\beta}_c\mathbf{C} + \boldsymbol{\varepsilon} \quad (3)$$

$$\mathbf{Y} = \boldsymbol{\beta}_p\mathbf{P} + \boldsymbol{\beta}_c\mathbf{C} + \boldsymbol{\varepsilon} \quad (4)$$

$$\mathbf{Y} = \boldsymbol{\beta}_e\mathbf{E} + \boldsymbol{\beta}_c\mathbf{C} + \boldsymbol{\varepsilon} \quad (5)$$

$$\mathbf{Y} = \boldsymbol{\beta}_r\mathbf{R} + \boldsymbol{\beta}_c\mathbf{C} + \boldsymbol{\varepsilon} \quad (6)$$

Where:

- **Y** is the (n × 1) vector, where n = 100, indicating the share of budget allocation devoted to the environmental issues, according to alternative specifications (*M-environment, P-environment* and *M10*).
- **D** is the (n × 2) matrix of the proxies for the demand for environmental quality and $\boldsymbol{\beta}_d$ is the (2 x 1) vector of respective unknown parameters.
- **A** is the (n × 3) matrix of agricultural sector variables and $\boldsymbol{\beta}_a$ is the (3 × 1) vector of respective unknown parameters.
- **P** is the (n × 2) matrix of politics and polity variables and $\boldsymbol{\beta}_p$ is the (2 × 1) vector of respective unknown parameters.
- **E** is the (n × 4) matrix of environmental-quality variables and $\boldsymbol{\beta}_e$ is the (4 × 1) vector of respective unknown parameters.
- **R** is the (n × 1) vector of decentralization variable and $\boldsymbol{\beta}_r$ is the respective unknown parameter,
- **C** is the (n × 2) matrix of control variables and $\boldsymbol{\beta}_c$ is the (2 × 1) vector of respective unknown parameters.
- $\boldsymbol{\varepsilon}$ is the (n × 1) vector of error terms.

The implementation of the fractional regression models was performed by using the software R (R Core Team, 2021).

4. RESULTS AND DISCUSSION

Table 3 reports the results of all the models. Across model specifications, three are the most robust results. First, the results indicate that *GDP* is positively correlated with the budget allocated to environmental goals (see section 3 for the description of the dependent variables). This result is in line with the large literature on the relationship between economic development and environmental quality (Grossman and Krueger, 1995) and with previous results on the political economy determinants of the stringency of environmental regulations to agricultural activities (Fredriksson and Svensson, 2003). Note that even *expenditures* on agri-environmental measures are found to be positively correlated to the GDP per capita of the area (e.g. Bertoni and Olper, 2012). The result is robust to the model specification being positive and significant also when *GDP* is isolated from the other variables (model 2) and with different specification of the dependent variables (P-environment and M-10). The odd ratios (Table 4) indicate that an increase by €1000 in GDP per capita induces an increase by 3.2% in the budget allocated to M-environment. Second, *DENSITY* is negatively correlated to budget for environmental goals. This is in contrast with our expectations, i.e., on the intuition that more urbanized areas would have demanded for a higher allocation of funds to the environmental goals. One interpretation of this result might lie in the idea that, at the EU level, population density actually captures other dimensions than per capita income, both in the North and in the South of the continent. The odd ratios indicate that additional 1000 inhabitants per square kilometre translate in a large reduction for the environmental budget (M-environment) (almost by 91%), an effect that is larger than the (positive) effect of *GDP*.

Third, decentralization (*NUTS*) is negatively correlated to the environmental budget. The dummy indicating a subnational polity is statistically significant and negatively correlated to the environmental budget share in any model specification. The literature on the topic is rather ambiguous and finds that the impact of decentralization on the allocation of funds to the environmental goals depends on the type of pollutants taken into account (Fredriksson and Wollscheid, 2014; Sigman, 2014, 2005). In our case, the result seems to indicate that decentralization would lead to a race to the bottom (Millimet, 2003) in allocating environmental budgets in the RDPs. While further analyses are required to understand the mechanisms behind it, such a result can also be interpreted in terms of governance scope (Schakel, 2009). For example, in Italy only some policy aspects are delegated to regional administration (health policies, for example), and hence, probably, a greater grip from lobbying is on them. The odd ratios suggest that decentralization has a strong effect: the delegation to lower government tiers induce a reduction in the budget allocated to *M-environment*, *P-environment* and *M-10* by respectively 61%, 45% and 36%.

Turning to the politics aspect of our problem, the number of parties that compose a cabinet is negatively correlated to the different proxies for environmental budgets (and significant in most of the models' specifications). This might suggest that environmental public goods require greater political coherence, in order to be funded. However, ideology seems not to be linked to any preferences for environmental budget allocation, as the coefficient for LEFT_RIGHT is non-significant. However, the effect of politics on budget allocations deserves a more comprehensive analyses, where e.g. electoral incentives are explicitly accounted for (List and Sturm, 2006; Pacca et al., 2020). Moreover, we only consider the government coalition in charge of the first version of the RDPs, to better address the effect of ideology it would be interesting to assess how changes in the government coalitions impact on the RDP budget allocations.

Surprisingly, the proxies for the bargaining power of the agricultural sector are all non-significant in any model specifications. To this regard, it is important to consider that we are analysing fund allocation among different goals but whose ultimate target is anyhow the agricultural sector. Probably, farmers preferences among the goals gets watered and no clear priority emerges. Note however that, when focusing on real expenditures rather than allocations, Zasada et al. (2018) also find that the agricultural bargaining power (proxied by the share of agricultural area) have little explanatory power. Similarly, Bertoni and Olper (2012) find a complex relationship between share of population working in agriculture and expenditures devoted to agri-environmental schemes.

Finally, a complex picture is drawn from the analysis of the agri-environmental conditions. The HNV and the nitrogen surplus are respectively negatively and positively correlated to the share of budget allocated to *M10*. When considering the other two dependent variables, the signs of the coefficients are reversed. This difference might be due to the different characteristics of each dependent variable under consideration. Actually, while measure 10 only supports activities that are strictly linked to agri-environmental measures and that represent a cost from the farmers point of view, other dependent variables encompass a broader set of interventions, including investments for higher resource efficiency.

5. CONCLUSIONS AND POLICY RECOMMENDATIONS

In this work, we analyse the political economy determinants of the share of the budget allocated for environmental goals in the EU RDPs, by considering the 2014-2020 programming period. The main idea is that such a budget is the result of some main determinants: i) demand of environmental quality, ii) bargaining power of the agricultural sector, iii) characteristics of the politics of the RDPs managing authorities, iv) environmental quality of the area; and v) tier levels of the RDPs managing authorities (national vs subnational levels). While a substantial literature has addressed the political economy of the support to the agriculture, very little has been said on the determinants of policies targeting the sustainability of the agricultural sector. In comparison to previous articles – which mostly addressed the determinants of the ex-post expenditures on agri-environmental schemes – the focus on budget allocation allows us to put a greater emphasis on the determinants of the political decision process behind the choice of allocating funds to the environmental goals rather than to other goals (often competing with each other).

Table 3. Results of the models (robust standard errors in parentheses).

	M-environment						P-environment						M-10					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
(Intercept)	0.243	-1.571 ***	-0.558 *	-0.789 *	-0.835 **	-0.108	0.903 *	-0.292 °	0.268 °	0.322 *	0.301 *	0.613 ***	-2.005 ***	-2.629 ***	-1.908 ***	-2.207 ***	-1.676 ***	-1.325 ***
	(0.774)	(0.268)	(0.251)	(0.310)	(0.284)	(0.224)	(0.373)	(0.150)	(0.149)	(0.158)	(0.140)	(0.131)	(0.411)	(0.192)	(0.235)	(0.187)	(0.165)	(0.208)
Density	-2.401 *	-2.450 *					-0.699 *	-0.613					-0.872 **	-0.927 **				
	(1.192)	(1.085)					(0.330)	(0.463)					(0.268)	(0.326)				
GDP	0.032 °	0.035 ***					0.019 *	0.019 **					0.017 °	0.035 ***				
	(0.016)	(0.010)					(0.009)	(0.006)					(0.009)	(0.007)				
UAA_share	-0.514		-0.920				-0.148		-0.246				0.204		0.414			
	(0.794)		(0.751)				(0.412)		(0.395)				(0.490)		(0.575)			
Farm per mill inhab	-0.002		0.003				0.000		0.000				-0.003		-0.007			
	(0.005)		(0.005)				(0.002)		(0.002)				(0.003)		(0.004)			
GVA_share	-0.020		-0.032				-0.009		-0.027				0.033		0.005			
	(0.057)		(0.064)				(0.029)		(0.031)				(0.037)		(0.051)			
Parties	-0.270 ***			-0.077			-0.151 ***			-0.077 °			0.022			0.096 °		
	(0.075)			(0.094)			(0.040)			(0.045)			(0.054)			(0.057)		
Left_right	-0.066			-0.023			-0.058 *			-0.026			0.040			0.045		
	(0.053)			(0.047)			(0.025)			(0.024)			(0.034)			(0.036)		
N_sur_kg_ha	0.004				-0.003		-0.001				-0.003		0.007 **				0.006 *	
	(0.005)				(0.006)		(0.003)				(0.003)		(0.002)				(0.003)	
Animals_ab	-0.225				-0.102		-0.072				-0.041		-0.107 °				-0.029	
	(0.172)				(0.185)		(0.069)				(0.093)		(0.057)				(0.071)	
HNV	0.015 *				0.015 *		0.007 *				0.006 °		-0.010 *				-0.010 *	
	(0.006)				(0.007)		(0.003)				(0.003)		(0.005)				(0.005)	
Erosion moderate-severe	-0.008				-0.016 **		-0.006 *				-0.010 ***		-0.003				-0.008 °	
	(0.006)				(0.006)		(0.003)				(0.003)		(0.005)				(0.004)	
NUTS	-0.950 **					-0.938 ***	-0.593 ***					-0.558 ***	-0.442 *					-0.565 **
	(0.341)					(0.216)	(0.160)					(0.134)	(0.187)					(0.200)
Pop	0.007	0.018	0.002	0.007	0.006	-0.015	-0.001	0.002	0.000	0.003	0.003	-0.007	0.009	0.025	0.023	0.023	0.007	0.015
	(0.025)	(0.022)	(0.019)	(0.019)	(0.020)	(0.020)	(0.010)	(0.010)	(0.009)	(0.009)	(0.010)	(0.008)	(0.015)	(0.015) °	(0.016)	(0.015)	(0.013)	(0.014)
EEC	-0.996 **	-0.479	-0.562 °	-0.408	-0.708 *	-1.208 ***	-0.639 **	-0.247 *	-0.328 *	-0.257 *	-0.485 **	-0.793 ***	-0.478 °	-0.070	-0.116	-0.432	-0.209	-0.732 *
	(0.380)	(0.299)	(0.317)	(0.286)	(0.324)	(0.824)	(0.198)	(0.126)	(0.135)	(0.126)	(0.148)	(0.157)	(0.287)	(0.255)	(0.264)	(0.271)	(0.252)	(0.285)
Obs.deleted (missing)	4	0	0	4	3	0	4	0	0	4	3	0	4	0	0	4	3	0
Efron pseudo R-squared	0.402	0.233	0.055	0.030	0.091	0.142	0.389	0.144	0.066	0.078	0.131	0.161	0.384	0.239	0.089	0.076	0.204	0.136

Table 4. Results of the models – odd ratios.

	M-environment						P-environment						M-10					
	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)	(1)	(2)	(3)	(4)	(5)	(6)
(Intercept)	1.275	0.208	0.572	0.454	0.434	0.898	2.466	0.747	1.307	1.380	1.352	1.846	0.135	0.072	0.148	0.110	0.187	0.266
Density	0.091	0.086					0.497	0.542					0.418	0.396				
GDP	1.032	1.036					1.019	1.019					1.017	1.035				
UAA_share	0.598		0.398				0.863		0.782				1.227		1.513			
Farm per mill inhab	0.998		1.003				1.000		1.000				0.997		0.993			
GVA_share	0.981		0.969				0.991		0.973				1.034		1.005			
Parties	0.764			0.926			0.860			0.926			1.022			1.101		
Left_right	0.936			0.977			0.944			0.974			1.041			1.047		
N_sur_kg_ha	1.004				0.997		0.999				0.997		1.007				1.006	
Animals_ab	0.798				0.903		0.931				0.960		0.898				0.972	
HNV	1.015				1.015		1.007				1.006		0.990				0.990	
Erosion moderate-severe	0.992				0.984		0.994				0.990		0.997				0.992	
NUTS	0.387					0.391	0.553					0.572	0.643					0.569
Pop	1.007	1.019	1.002	1.007	1.006	0.985	0.999	1.002	1.000	1.003	1.003	0.993	1.009	1.025	1.023	1.024	1.007	1.015
EEC	0.369	0.619	0.570	0.665	0.493	0.299	0.528	0.781	0.720	0.773	0.616	0.452	0.620	0.932	0.890	0.649	0.812	0.481

The analysis shows that the determinants behind the allocation of the European Rural Development Policy budget to environmental goals are similar to those found in the literature concerning environmental policies in general. The results seem to show the critical role played by an increase in the average wealth (as proxied by GDP per capita) favouring a larger environmental support. This result is not new – being in line with previous literature– but it is confirmed also for the EU RDP. Moreover, different proxies for the lobbying power of the agricultural sector (as proxied by the UAA, the number of farms, and the agricultural GVA) show no significance, hence the supposed competition between the agricultural support on the one hand and a broader support toward multifunctionality, and the environment in particular, on the other does not find strong support. Decentralization is linked to lower budgets allocated to environmental goals and display a strong effect.

The combination of the effect of per capita income and of decentralization seems to suggest that delegating RDPs management to subnational authorities might be particularly problematic, given the high heterogeneity of development across European regions. The results seem to indicate that, if environmental issues are at stake, maintaining a relatively centralized grip on the environmental budget would be desirable. To this regard, the decision undertaken in the implementation of the current 2021-2027 RDPs can be considered as positive for the implementation of a policy more in favour of agri-environmental targets. Indeed, the Regulation No 2115/2021 sets that all new rural development actions will be incorporated into national-level CAP strategic plans, establishing specific rules on support for strategic plans to be drawn up by EU countries under the common agricultural policy.

The emerging results are insightful, despite the existence of some possible shortcomings in the work. For example, the choice of a cross-sectional analysis, rather than a panel one, might somehow affect this analysis, due to the potential presence of unobserved heterogeneity. However, it seems not possible to compare expenditure patterns across different programming periods, due to the large changes that have always affected Rural Development Policy over time. Thus, further analysis will not only address these possible flaws. It should also seek to further disentangle the drivers of environmental budget allocation, including robustness checks, such as controlling for alternative proxies for the main effects admitted at impacting the environmental budget allocation, and a throughout assessment of the effect of government party's composition on it.

6. REFERENCES

Aitchison, J., 1986. The statistical analysis of compositional data. Chapman & Hall, Ltd., GBR.

Anderson, K., Rausser, G., Swinnen, J., 2013. Political Economy of Public Policies: Insights from Distortions to Agricultural and Food Markets. Journal of Economic Literature 51, 423–477. https://doi.org/10.1257/jel.51.2.423

Bareille, F., Zavalloni, M., 2020. Decentralisation of agri-environmental policy design. European Review of Agricultural Economics 47, 1502–1530. https://doi.org/10.1093/erae/jbz049

Batool, M., Sarrazin, F.J., Attinger, S., Basu, N.B., Van Meter, K., Kumar, R., 2022. Long-term annual soil nitrogen surplus across Europe (1850–2019). Scientific Data 9, 612. https://doi.org/10.1038/s41597-022-01693-9

Baylis, K., Peplow, S., Rausser, G., Simon, L., 2008. Agri-environmental policies in the EU and United States: A comparison. Ecological Economics 65, 753–764. https://doi.org/10.1016/j.ecolecon.2007.07.034

Beckmann, V., Eggers, J., Mettepenningen, E., 2009. Deciding how to decide on agri-environmental schemes: the political economy of subsidiarity, decentralisation and participation in the European Union. Journal of Environmental Planning and Management 52, 689–716. https://doi.org/10.1080/09640560902958289

Beghin, J.C., Kherallah, M., 1994. Political Institutions and International Patterns of Agricultural Protection. The Review of Economics and Statistics 76, 482–489. https://doi.org/10.2307/2109973

Bellemare, M.F., Carnes, N., 2015. Why do members of congress support agricultural protection? Food Policy 50, 20–34. https://doi.org/10.1016/j.foodpol.2014.10.010

Bertoni, D., Olper, A., 2012. The political economy of agri-environmental measures: An empirical assessment at the eu regional level. Applied Studies in Agribusiness and Commerce 6, 71–82. https://doi.org/10.19041/APSTRACT/2012/3-4/10

Cain, Z., Lovejoy, S., 2004. History and Outlook for Farm Bill Conservation Programs. Choices 19, 37–42.

Camaioni, B., Coderoni, S., Esposti, R., Pagliacci, F., 2019. Drivers and indicators of the EU rural development expenditure mix across space: Do neighbourhoods matter? Ecological Indicators 106, 105505. https://doi.org/10.1016/j.ecolind.2019.105505

Camaioni, B., Esposti, R., Lobianco, A., Pagliacci, F., Sotte, F., 2013. How rural is the EU RDP? An analysis through spatial fund allocation. Bio-based and Applied Economics 2, 277–300. https://doi.org/10.13128/BAE-13092

Camaioni, B., Esposti, R., Pagliacci, F., Sotte, F., 2016. How does space affect the allocation of the EU Rural Development Policy expenditure? A spatial econometric assessment. European Review of Agricultural Economics 43, 433–473. https://doi.org/10.1093/erae/jbv024

Crippa, M., Solazzo, E., Guizzardi, D., Monforti-Ferrario, F., Tubiello, F.N., Leip, A., 2021. Food systems are responsible for a third of global anthropogenic GHG emissions. Nature Food 2, 198–209. https://doi.org/10.1038/s43016-021-00225-9

Dasgupta, S., De Cian, E., 2018. The influence of institutions, governance, and public opinion on the environment: Synthesized findings from applied econometrics studies. Energy Research & Social Science, Sustainable energy transformations in an age of populism, post-truth politics, and local resistance 43, 77–95. https://doi.org/10.1016/j.erss.2018.05.023

Dasgupta, S., Laplante, B., Wang, H., Wheeler, D., 2002. Confronting the Environmental Kuznets Curve. The Journal of Economic Perspectives 16, 147–168.

Dinda, S., 2004. Environmental Kuznets Curve Hypothesis: A Survey. Ecological Economics 49, 431–455. https://doi.org/10.1016/j.ecolecon.2004.02.011

Döring, H., Manow, P., 2020. Parliaments and governments database (ParlGov): Information on parties, elections and cabinets in modern democracies. Development version. http://www.parlgov.org/.

Droste, N., Ring, I., Santos, R., Kettunen, M., 2018. Ecological Fiscal Transfers in Europe – Evidence-Based Design Options for a Transnational Scheme. Ecological Economics 147, 373–382. https://doi.org/10.1016/j.ecolecon.2018.01.031

Fałkowski, J., Olper, A., 2014. Political competition and policy choices: the evidence from agricultural protection. Agricultural Economics 45, 143–158. https://doi.org/10.1111/agec.12018

Franzen, A., Vogl, D., 2013. Two decades of measuring environmental attitudes: A comparative analysis of 33 countries. Global Environmental Change 23, 1001–1008. https://doi.org/10.1016/j.gloenvcha.2013.03.009

Fredriksson, P.G., Svensson, J., 2003. Political instability, corruption and policy formation: the case of environmental policy. Journal of Public Economics 87, 1383–1405. https://doi.org/10.1016/S0047-2727(02)00036-1

Fredriksson, P.G., Wollscheid, J.R., 2014. Environmental decentralization and political centralization. Ecological Economics 107, 402–410. https://doi.org/10.1016/j.ecolecon.2014.09.019

Glebe, T., Salhofer, K., 2007. EU agri-environmental programs and the “restaurant table effect.” Agricultural Economics 37, 211–218. https://doi.org/10.1111/j.1574-0862.2007.00267.x

Grossman, G.M., Krueger, A.B., 1995. Economic Growth and the Environment. The Quarterly Journal of Economics 110, 353–377. https://doi.org/10.2307/2118443

Guerrero, S., 2021. Characterising agri-environmental policies: Towards measuring their progress (No. 155), OECD Food, Agriculture and Fisheries Paper. OECD.

Hackl, F., Halla, M., Pruckner, G.J., 2007. Local compensation payments for agri-environmental externalities: a panel data analysis of bargaining outcomes. European Review of Agricultural Economics 34, 295–320. https://doi.org/10.1093/erae/jbm022

Hellerstein, D.M., 2017. The US Conservation Reserve Program: The evolution of an enrollment mechanism. Land Use Policy 63, 601–610. https://doi.org/10.1016/j.landusepol.2015.07.017

Klomp, J., Haan, J. de, 2013. Conditional Election and Partisan Cycles in Government Support to the Agricultural Sector: An Empirical Analysis. American Journal of Agricultural Economics 95, 793–818. https://doi.org/10.1093/ajae/aat007

List, J.A., Sturm, D.M., 2006. How Elections Matter: Theory and Evidence from Environmental Policy. The Quarterly Journal of Economics 121, 1249–1281.

López and, R., Mitra, S., 2000. Corruption, Pollution, and the Kuznets Environment Curve. Journal of Environmental Economics and Management 40, 137–150. https://doi.org/10.1006/jeem.1999.1107

Maddison, D., 2006. Environmental Kuznets curves: A spatial econometric approach. Journal of Environmental Economics and Management 51, 218–230. https://doi.org/10.1016/j.jeem.2005.07.002

Mamun, A., Martin, W., Tokgoz, S., 2021. Reforming Agricultural Support for Improved Environmental Outcomes. Applied Economic Perspectives and Policy aepp.13141. https://doi.org/10.1002/aepp.13141

Matthews, A., 2013. Greening agricultural payments in the EU’s common agricultural policy. Bio-based and Applied Economics 2, 1–27.

Matthews, A., Salvatici, L., Scoppola, M., 2017. Trade impacts of agricultural support in the EU. IATRC Commissioned Paper 19 120.

Millimet, D.L., 2003. Assessing the Empirical Impact of Environmental Federalism. Journal of Regional Science 43, 711–733. https://doi.org/10.1111/j.0022-4146.2003.00317.x

OECD, 2020. Agricultural Policy Monitoring and Evaluation 2020, Agricultural Policy Monitoring and Evaluation. OECD. https://doi.org/10.1787/928181a8-en

OECD, 2016. OECD’S producer support estimate and related indicators of agricultural support. Concepts,

Calculations, Interpretation and Use (The PSE Manual). OECD Trade and Agriculture Directorate.
Olper, A., 2007. Land inequality, government ideology and agricultural protection. Food Policy 32, 67–83. https://doi.org/10.1016/j.foodpol.2006.03.009
Olper, A., Fałkowski, J., Swinnen, J., 2014. Political Reforms and Public Policy: Evidence from Agricultural and Food Policies. The World Bank Economic Review 28, 21–47. https://doi.org/10.1093/wber/lht003
Olson, M., 1971. The Logic of Collective Action: Public Goods and the Theory of Groups. Harvard University Press. https://doi.org/10.2307/j.ctvjsf3ts
Pacca, L., Curzi, D., Rausser, G., Olper, A., 2020. The Role of Party Affiliation, Lobbying and Electoral Incentives in Decentralized U.S. State Support of the Environment. Journal of the Association of Environmental and Resource Economists 711583. https://doi.org/10.1086/711583
Papke, L.E., Wooldridge, J.M., 1996. Econometric methods for fractional response variables with an application to 401(k) plan participation rates. Journal of Applied Econometrics 11, 619–632. https://doi.org/10.1002/(SICI)1099-1255(199611)11:6<619::AID-JAE418>3.0.CO;2-1
Perotti, R., Kontopoulos, Y., 2002. Fragmented fiscal policy. Journal of Public Economics 86, 191–222. https://doi.org/10.1016/S0047-2727(01)00146-3
Polk, J., Rovny, J., Bakker, R., Edwards, E., Hooghe, L., Jolly, S., Koedam, J., Kostelka, F., Marks, G., Schumacher, G., Steenbergen, M., Vachudova, M., Zilovic, M., 2017. Explaining the salience of anti-elitism and reducing political corruption for political parties in Europe with the 2014 Chapel Hill Expert Survey data. Research & Politics 4, 2053168016686915. https://doi.org/10.1177/2053168016686915
R Core Team, 2021. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna.
Ramalho, E.A., Ramalho, J.J.S., Murteira, J.M.R., 2011. Alternative Estimating and Testing Empirical Strategies for Fractional Regression Models. Journal of Economic Surveys 25, 19–68. https://doi.org/10.1111/j.1467-6419.2009.00602.x
Ronning, G., 1990. Share equations in econometrics: A story of repression, frustation and dead ends (Diskussionsbeiträge - Serie II No. 118). Universität Konstanz, Sonderforschungsbereich 178 - Internationalisierung der Wirtschaft, Konstanz.
Schakel, A.H., 2013. Congruence Between Regional and National Elections. Comparative Political Studies 46, 631–662. https://doi.org/10.1177/0010414011424112
Schakel, A.H., 2009. Explaining policy allocation over governmental tiers by identity and functionality. Acta Politica 44, 385–409. https://doi.org/10.1057/ap.2009.9
Schakel, A.H., Massetti, E., 2018. A world of difference: the sources of regional government composition and alternation. West European Politics 41, 703–727. https://doi.org/10.1080/01402382.2017.1400237
Shobe, W., 2020. Emerging Issues in Decentralized Resource Governance: Environmental Federalism, Spillovers, and Linked Socio-Ecological Systems. Annual Review of Resource Economics 12, 259–279. https://doi.org/10.1146/annurev-resource-110319-114535
Sigman, H., 2014. Decentralization and Environmental Quality: An International Analysis of Water Pollution Levels and Variation. Land Economics 90, 114–130. https://doi.org/10.3368/le.90.1.114
Sigman, H., 2005. Transboundary spillovers and decentralization of environmental policies. Journal of Environmental Economics and Management 50, 82–101. https://doi.org/10.1016/j.jeem.2004.10.001
Swinnen, J.F.M., 1994. A Positive Theory of Agricultural Protection. American Journal of Agricultural Economics 76, 1–14. https://doi.org/10.2307/1243915
Swinnen, J.F.M., Goter, H. de, Rausser, G.C., Banerjee, A.N., 2000. The political economy of public research investment and commodity policies in agriculture: an empirical study. Agricultural Economics 22, 111–122. https://doi.org/10.1111/j.1574-0862.2000.tb00009.x
Zasada, I., Weltin, M., Reutter, M., Verburg, P.H., Piorr, A., 2018. EU's rural development policy at the regional level—Are expenditures for natural capital linked with territorial needs? Land Use Policy 77, 344–353. https://doi.org/10.1016/j.landusepol.2018.05.053

BAE
Bio-based and Applied Economics

AIEAA
ASSOCIAZIONE ITALIANA DI
ECONOMIA AGRARIA E APPLICATA

OPEN ACCESS

Citation: Farsi Aliabadi, M.M., & Fakari Sardehaie, B. (2024). Economic sanctions and barley price regime change in Iran. *Bio-based and Applied Economics* 13(2): 161-170. doi: 10.36253/bae-14542

Received: March 25, 2023
Accepted: March 09, 2024
Published: July 25, 2024

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Editor: Simone Cerroni

ORCID
MF: 0000-0002-6650-7344
BF: 0000-0003-3646-3421

Economic sanctions and barley price regime change in Iran

Mohammad Mehdi Farsi Aliabadi*, Behzad Fakari Sardehaie

Water and Agricultural Strategic Research Center (NWASRC) of ICCIMA, Tehran, Iran
* Corresponding author. E-mail: mm_farsi22@yahoo.com

Abstract. In Iran, barley is considered the second-largest cultivated crop. However, more than 40% of Iran's requirements are imported from the international market. Due to the importance of barley in providing livestock feed and food security, its price variation is a critical issue for Iranian governments. Therefore, in this study, the influence of different determinants of domestic barley price, such as international price, real effective exchange rate variation, price volatility of barley, Russian-Ukrainian armed conflict, and the existence of economic sanctions, has been investigated by applying the Markov-Switching model. The main results indicated that in both states, the real effective exchange rate was the primary determinant of the domestic price. Moreover, the impact of international price in first state is much more powerful than the second state. Also, the results revealed that the persistence of US economic sanctions amplified barley prices in both regimes. According to these findings, the government should eliminate interventions in the barley market by utilizing the preferential exchange rate for importing barley. Moreover, pursuing a political agenda to create a stable political condition and lift economic sanctions should be considered the priority for the government to mitigate the barley price upsurge.

Keywords: barley price, regime change, GARCH, Markov-Switching.
JEL Codes: Q2, Q18, C24.

1. INTRODUCTION

In last decades, agricultural markets witnessed a significant boom-bust cycle and excessive price volatility from 2006 to 2014 (Guo and Tanaka, 2019; Ott and Ott, 2014), and this trend was the primary critical economic and food security challenge. Moreover, the consequences of food price hikes and exacerbated price volatility can go beyond the economics and food security matters and have social and political repercussions (Bhagowalia et al., 2012). Periods of high or low prices are not new; however, in recent years, the magnitude of price fluctuation and its geographical expansion have been substantial (Bhagowalia et al., 2012). Therefore, investigating the trend of increasing market instability for agricultural commodity markets and its impact on commodity prices has become a priority on the international agenda (Magrini et al., 2017).

Firenze University Press | www.fupress.com/bae

The excessive change in the price of agricultural commodities creates a situation of uncertainty that can have an enormous influence on all the actors, such as consumers, producers, investors, merchants, and government, especially in developing countries (Fakari et al., 2013; Danehsvar Kakhki et al., 2019; Mittal and Hariharan, 2018). Consumers in developing countries spend a considerable share of their income on food; hence, they are sensitive to food price fluctuation (Cedrez et al., 2020; Farsi Aliabadi et al., 2021). On the other hand, the profitability of farming activity and incentives for producers' investment depend on market prices, and producers' decisions face a high degree of uncertainty in such a condition (Cedrez et al., 2020). Additionally, price volatility can generate a higher cost of agricultural commodity trade due to irregularity in the market and inflation pressure (Daneshvar Kakhkiet al., 2019). Therefore, price volatility negatively affects household welfare; Layani et al. (2020) indicated that an additional 1.79 percent of urban households drop below the poverty line due to a 9.8 percent increase in food prices. High Price variation also imposes substantial pressure on the government to control and stabilize the market prices to satisfy the country's food security objectives (Pieters and Swinnen, 2016). Due to these negative impacts, it's essential to identify the nature and reasons for price volatility, which can be helpful in reducing the distractive impact and controlling food prices (Fakari et al., 2016).

The Iranian government has always aimed to prevent price amplification in the agricultural sector due to its negative impact on economic activities. For this purpose, they have implemented a price stabilization policy, where essential commodities such as wheat, sugar, and barley are the central concerns. However, despite the policy, the price of agricultural commodities has increased significantly in recent years due to high inflation, currency weakness, and other macroeconomic difficulties. Therefore, it is crucial to identify influential contributors to the rising prices in Iran (Mehdizadeh Rayeni et al., 2022).

A vast number of studies focused on investigating and understanding the determinants of agricultural prices (Dinku and Worku, 2022; Iqbal et al., 2022; Steen et al., 2023). It's clear that the joint influence of a plethora of causes generates price variation (Santeramo and Lamonaca, 2019). Biofuel production, energy prices, climate change, condition of financial markets, exchange rate, monetary policies, interest rate, transaction cost, sudden trade restriction, agricultural policies, and increase in food demand are considered as the influential factors that amplified the food prices and its variability (Cinar, 2018; Eissa and Al Refai, 2019; Lanfranchi et al., 2019, Uçak et al., 2022). In the last decade, the influence of exchange rates and international market prices on the dynamics of agricultural food prices in the domestic market has been well documented (Mosavi et al., 2014; Hájek and Horváth, 2016; Clapp et al., 2017; Braha et al., 2019; Lanfranchi et al., 2019; Sadiq et al., 2021). While the exchange rate variation affects the price of imported and exported agricultural commodities and also has significant consequences for countries relative prices (Adekunle and Ndukwe, 2018), the level of the relation among prices in global and regional markets totally depends on market integration and trade policy (Brown and Kshirsagar, 2015; Ganneval, 2016; Bekkers et al., 2017; Baffes et al., 2019;). Therefore, investigating the prices that pass-through exchange rates and international prices for each commodity in each region could be a vital matter for consumers, producers, importers, and policymakers. Alongside these traditional deriving forces, political unrest such as sanctions and war has been considered a substantial factor, which leads to food price inflation and fluctuation in international and domestic markets (Sohag et al., 2023). Since February 2022, the Russian invasion of Ukraine and this armed conflict have become a driving force of price volatility (Nasir et al., 2022). Grain production reduction in these predominant producers, trade restrictions, and fuel and fertilizer price spikes are a few reasons that caused agricultural price instability due to the Russian-Ukrainian conflict (Aliu et al., 2023). Therefore, this factor also should be taken into consideration.

Barley crop is the fourth most important cereal in the world, after wheat, corn, and rice. Nowadays, barley is consumed as animal feed, and around 70% of barley production is utilized for this purpose, 21% for malting, and less than 6% is directly consumed as human food (Tricase et al., 2018). In Iran, barley is the second largest crop by area, averaging 1.6 million hectares over the last five years, with production around 3 million tons (Motamed, 2017). Despite a large amount of production, the domestic production does not meet the country's requirement; thus, the deficiency is compensated by import (Daneshvar Kakhki et al., 2019), and in recent years, more than 40% of barley requirements have been imported from international market (AWNRC, 2020).

Due to the importance of barley in providing livestock feed and food security, price variation of barley is a predominant issue for Iranian governments. Moreover, a strong connection has existed between domestic and international markets due to the high share of imports in providing domestic requirements (Sadiq et al., 2021). In this context, the price variation in the global market due to political unrest in major producing countries might lead to significant changes in domestic barley prices (Mohammadi et al., 2016; Daneshvar kakhki et al., 2019). Moreover, other factors which have an influence on barley import, such as exchange rate, trade policy and restriction, and international sanctions, might cause price volatility in domestic prices and have a negative impact on food security (Mohammadi et al., 2016; Hejazi Emamgholipour, 2022; Zamanialaei et al., 2023). Even though some studies have been devoted to investigating the impact of different factors on food price variation, only a few have analyzed the influence of determinants of barley price in the domestic market, and to the best of knowledge no study has paid attention to the possible nonlinear behavior of barley price in Iran. Therefore, the objective of this study is to investigate the influence of international barley price, exchange rate variation, and local barley price volatility on the possible nonlinear behavior of domestic barley price in the era of maximum pressure campaign and Russian-Ukrainian military conflict to present a suitable approach for price management.

2. MATERIAL AND METHODS

This study has used time series data to investigate the possible regime change in barley prices under the US maximum pressure camping. For this purpose, a four-step procedure has been developed. In the first step, the time series should be tested to check the presence of the unit root test. For this purpose, we employed the Augmented Dickey-Fuller (ADF), Phillips-Perron, and Augmented Dickey-Fuller with structural break tests. If the series has a unit root, differencing should continue until the series becomes stationary. In the second step, Iran's barley price fluctuation should be extracted. To this end, an ARMA (Autoregressive Moving-Average Model) should be applied to Iran's barley price. Then, an LM (Lagrange Multiplier) test is conducted on the residual of the estimated ARMA model to check the ARCH (Autoregressive Conditional Heteroscedasticity) effect (Fakari et al., 2013). If the ARCH effect exists in the residual, the ARCH/GARCH (Generalized Autoregressive Conditional Heteroscedasticity) models will be applied to extract the domestic barley price volatility. The next step depends on the results of the unit root tests. If the variables are stationary in the first level, we can move to the last step and estimate the Markov-switching (MS) model. However, if the variables become stationary only after the first difference, then the Johanson co-integration test should be applied to check the existence of the Co-integration vector. Finally, if a co-integration vector exists, the Markov-switching model can be estimated.

2.1. Methods

2.1.1. ARCH/GARCH methods

In order to calculate Iran's Barley price volatility, first, the ARMA model should be estimated. The ARMA(p,q) (Autoregressive Moving-Average Model) general form includes a combination of the autoregressive and the moving average model and has been presented in equation (1).

$$y_t = \alpha + \sum_{i=1}^{p} \beta_i y_{t-i} + e_t \qquad (1)$$

The residual term (e_t) in equation (1) follows a moving average specification presented in equation (2).

Constant variance during the time is one of the main assumptions of classic econometric methods. However, in many cases, this assumption is not achievable or logical. In order to overcome this restriction, Engle (1982) and Bollerslev (1986) presented the ARCH/GARCH model. In this model, two equations are estimated for the mean and variance to model the volatilities. The basic equation for GARCH (q,p) is presented in equations (3) and (4).

$$y_t = \mu_t + \sigma_t z_t$$
$$\mu_t = \alpha + \sum_{i=1}^{k} \beta_i x_{i,t} \qquad i_t \sim NID(0,1) \qquad (2)$$

$$\sigma_t^2 = \tau_0 + \sum_{i=1}^{q} \tau_i \varepsilon_{t-i}^2 + \sum_{i=1}^{p} \theta_i \sigma_{t-i}^2 \qquad \varepsilon_t \sim NID(0,H_t) \qquad (3)$$

In the first equation, Y_t is the conditional mean which depends on explanatory variables that are shown by $X_{i,t}$, and Z_t is the residual term. The second equation is the variance equation, and the coefficients should be estimated. Equation (4), σ_t^2 is a linear function of its past values (σ_{t-1}^2) and the past values of squared innovations (ε_{t-1}^2) (Engle and Bollerslev, 1986).

2.1.2. Markov-Switching method

Many economic time series variables exhibit nonlinear behavior associated with the events or abrupt changes in government policies (Hamilton, 2018). In recent years, economic variables such as agricultural commodity prices showed a complex and nonlinear behavior, and it is difficult to capture the multiple states correlation that existed between these variables using the linear relationship of a single state (Lie et al., 2019; Kalligeris et al., 2021). To this end, this paper designed a relationship measurement model based on the Markov-switching approach, which can measure the multi-state dependence structure between dependent and independent variables.

Hamilton (1989) introduced the Markov-Switching models for time series. It is a powerful method for parameter estimation when economic variable behaves differently in different states of nature or regimes (De la Torre-Torres et al., 2020). In other words, the MS model permits the time series variables to exhibit periodic shifts in their observed behavior between two regimes. The features of different regimes, such as regime duration and transition possibilities, have been determined endogenously (Valera and Lee, 2016). This study has assumed that domestic barley price switches between two unobservable states. Furthermore, it is supposed that the transition from one state to the other follows a Markov process, and the time transition and the duration in each state are random.

In this study, the following model is specified:

$$DBP_t = C_s + X_t\alpha + Z_t\beta_S + \epsilon_{St} \quad (4)$$

Where DBP_t represents the barley price in the domestic market, t accounts for time (month), and S represents the unobserved states (s= 1,2). C_s is a state dependence intercept, X_t is a matrix of state invariant variables, Z_t is a matrix of state-dependent variables, and $\epsilon_{St} \sim iidN(0,\sigma^2_s)$ is the error term. The model also can be written in the following order:

$$DBP_t = \begin{cases} C_1 + \sum_{i=1}^{n} \alpha_i DBP_{t-i} + \beta_{11}WP_t + \beta_{21}RER_t + \beta_{31}VDP_t + \beta_{41}MPC_t + \beta_{51}RUC_t + \epsilon_{1t} & \text{If } s = 1 \\ C_2 + \sum_{i=1}^{n} \alpha_i DBP_{t-i} + \beta_{12}WP_t + \beta_{22}RER_t + \beta_{32}VDP_t + \beta_{42}MPC_t + \beta_{52}RUC_t + \epsilon_{2t} & \text{If } s = 1 \end{cases} \quad (5)$$

The conditional transition probability to switch from regime I in the current month to regime j in the next month is presented in the equation (7).

$$\Pr(S_{t+1} = j | S_t = i) = P_{ij} \quad (6)$$

Therefore, the two-state model used in this study will lead to the following probability matrix:

$$\begin{bmatrix} P_{11} & P_{12} \\ P_{21} & P_{22} \end{bmatrix} \quad (7)$$

with $P_{11} + P_{12} = 1$ and $P_{21} + P_{22} = 1$.

2.2. Data

The data used in this study consist of the monthly barley price of Iran's domestic barley price, international barley price, the real exchange rate, and barley price volatility in the domestic market from August 2009 to September 2023. This period was chosen because it covers the different US sanction regimes during the agricultural price escalation. Moreover, this period includes the international price spike of 2010-2011 and 2019-2020, which might lead to interesting results. The price of barley in the domestic market, the Real Effective Exchange Rate, based on the Consumer Price Index, and international barley prices are from the Statistical Centre of Iran (Statistical Center of Iran; Price index database, 2023) and IMF (IMF Data Base, 2023) respectively. The price volatility of barley in the domestic market is extracted from its time series using the ARCH/GARCH method. The index of geopolitical conflict, which can be considered an index of armed conflict between Russia and Ukraine, has been adapted from the study of Caldara and Iacoviello (2022). Finally, a dummy variable was considered in the analysis to capture the impact of the US maximum pressure campaign on domestic barley prices. Descriptions of the variables are presented in Table 1.

According to the statistics presented in Table 2, the prices of domestic barley have experienced significant fluctuations over time. In August 2009, the recorded price for domestic barley was 2004 Rials per ton, and it had increased to 111476 by September 2023, showing an average monthly growth rate of 2%. The minimum price for barley was recorded in March 2010, while the maximum price was registered in March 2023. The high standard deviation indicates that the domestic barley price has been extremely unstable.

It should be noted that all the variables are transformed to logarithmic form for further investigation.

Table 1. Description of the variables.

Name	Definition
DBP	Barley price in Iran domestic market
WP	Barley price in International Market
RER	Iran real effective exchange rate
VDP	Barley price volatility in Iran's domestic market
RUC	The average geopolitical risk of Russia and Ukraine adapted from Caldara and Iacoviello (2022).
MPC	Dummy variable equal to 1 during maximum pressure campaign and 0 otherwise

Source: Authors definition.

Table 2. Statistics of the variables.

Variables	Measurement unit	Mean	Maximum	Minimum	Std. Dev.
DBP	Rial per metric ton	24224.86	121353	1777	32699.65
WP	US$ per metric ton	151.48	262.95	83.04	52.88
REER	index	155.15	502.52	80.89	100.2
RUC	index	-0.16	1.71	-1.48	0.59

Source: Authors calculation.

3. RESULTS

The results of the ADF, and the Phillips-Perron, and ADF with the structural breaks unit root test are presented in Table 3. The results of all tests determined that the variables, except the Russian-Ukrainian conflict, were not stationary at the level. However, the unit root test revealed that the variables were stationary at the first difference.

The results of the mean equation, ARCH effect test, and GARCH estimation of domestic barley price are presented in tables 4. According to AIC (Akaike information criterion) and SIC (Schwarz information criterion) criteria, the ARIMA (2,1,0) was chosen as the best mean specification model. Then, the ARCH effect test was conducted, and its results revealed the existence of Heteroscedasticity. Therefore, the ARCH/GARCH model should apply to capture the domestic barley price volatility.

The domestic barley price volatility index is extracted from the GARCH model and presented in Figure (1). the main result indicates that the index experienced significant changes from November 2011 to November 2012 and intensified from May 2020 to May 2022. In Iran, the real exchange rate volatility can intensify the volatility of imported commodities such as barley. Moreover, since May 2020, the intensification of barley price volatility could be traced back to the impact of the U.S. maximum pressure campaign policy and the elimination of the preferential exchange rate policy.

Johanson's Co-integration test result indicated that all the variables are Co-integrated. Therefore, the level variables are employed to estimate the Markov-Switching model. The results of model estimation for two regimes are presented in Table 5.

The estimated coefficients for barley world price in both regimes indicated that this variable imposes a positive and statistically significant influence on domestic barley price. According to the results, a percent increase in world barley price increases the domestic price by 0.87 and 0.1 %. This result is to the findings of Moghadasi et al. (2011), Yousefi and Moghadasi (2013), Brown and Kshirsagar (2015), Bekkers et al. (2017), and

Table 3. Results of unit root tests.

Variables	t- Statistic	Result	Variables	t- Statistic	Result
ADF					
DBP	-1.38	No Stationary	Δ(DBP)	-4.8*	Stationary
WP	-1.92	No Stationary	Δ(WP)	-8.65*	Stationary
RER	-1.9	No Stationary	Δ(RER)	-9.53*	Stationary
RUC	-4.28*	Stationary			
PP					
DBP	-1.84	No Stationary	Δ(DBP)	-10.71	Stationary
WP	-1.63	No Stationary	Δ(WP)	-8.85	Stationary
RER	-1.95	No Stationary	Δ(RER)	-10.24	Stationary
RUC	-3.97*	Stationary			
ADF with Break					
DBP	-2.65	No Stationary	Δ(DBP)	-10.34	Stationary
WP	-3.24	No Stationary	Δ(WP)	-9.57	Stationary
RER	0.8	No Stationary	Δ(RER)	-11.38	Stationary
RUC	-3.98*	Stationary			

Source: Authors Calculation, *, ** and, *** indicate the level of significance for 1, 5 and, 10 percent.

Table 4. Mean equation, Heteroscedasticity Test and GARCH estimation of domestic barley price.

Mean Equation: ARIMA(2,1,0)				
Variables	Intercept	AR(1)	AR(2)	Goodness of Fit
DBP	0.23*	0.17*	-0.19*	Adjusted R2= 0.79 AIC= 2.13 SC=2.06
Heteroscedasticity Test: ARCH				
	F-statistic= 5.97*		Obs*R-squared=5.83*	
ARCH (1)				
	Intercept	RESID(-1)^2		Goodness of Fit
DBP	0.03*	0.17*		Adjusted R2= 0.86 AIC= 2.33 SC=2.24

Source: Authors Calculation; *, ** and, *** indicate the level of significance for 1, 5 and, 10 percent.

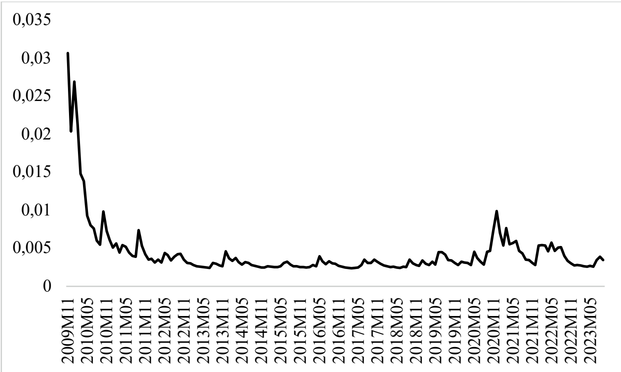


Figure 1. Trend of domestic barley price volatility index. Source: Authors calculation.

Daneshvar Kakhki et al. (2019). A comparison between the first and second state parameters indicated that the influence of world price declined significantly in the second regime. It is worth noting that State 1 is approximately simultaneous with the absence of economic pressure, and State 2 is virtually concurrent with the intensive economic sanction. In the first state, the government is less sensitive to controlling the prices; therefore, the domestic and international commodity markets are related significantly, and the world price is the significant determinant of domestic prices. However, during the maximum pressure campaign or intensive economic sanction, the government becomes more sensitive to price variation of essential commodities such as barley, and the price transmission from the international to the domestic market is considerably weak.

Based on the results, a real effective exchange rate has a positive and statistically significant impact on domestic barley prices. To be more specific, a percent increase in real effective exchange rate increases the domestic price by 1.67 and 1.97 % in the first and second regime, respectively. These results are in agreement with the results of Mohammadi et al. (2015), Ghahremanzadeh et al. (2020), Iqbal et al. (2022), and Sokhanvar and Bouri (2022). The estimated coefficients for dependent variables indicated the contribution of the real exchange rate is considered high in the formation of domestic barley prices in both states. Moreover, the influence of this variable in the second state intensified. It is worth noting that the availability of exchange rates through the formal market has become arduous during state 2. Moreover, the alternative mechanism for providing the exchange rate with the multiple exchange rate not only does not ease access but also aggravates an extra cost to traders because of the intensification of administrative bureaucracy. Therefore, the real exchange rate has a more powerful impact in this state.

Table 5. Markov-Switching estimation results for barley domestic price.

Dependent variable domestic price		
Variables	Regime 1	Regime 2
Intercept	2.01*	3.25*
WP	0.87*	0.1***
RER	1.67*	1.91*
VDP	0.36*	0.20*
MPC	0.1**	0.24*
RUC	0.01^{Ns}	0.07**
Goodness of Fit		
AIC= -0.88, SC=-0.76, DW=-0.60		

Source: Authors Calculation; *, ** and, *** indicate the level of significance for 1, 5 and, 10 percent.

The domestic price volatility of barley also imposes a positive and statistically significant influence on domestic prices in both states. The results also indicated that a percent increase in barley price volatility results in a growth in domestic barley prices with a magnitude of 0.36 and 0.2 % in the first and second regimes, respectively. Comparing the estimated coefficients in different regimes revealed that the barley domestic price volatility imposed a more powerful impact in the first state. As it has been mentioned earlier in the first state, the government was not sensitive to price variation of essential commodities, and price volatility management was not the main administration priority; therefore, the domestic price fluctuation imposed a more powerful impact on barley price.

The maximum pressure campaign also has a positive and statistically significant impact on domestic barley prices, which is consistent with the results of Ghahremanzadeh et al. (2020). While the influence of the maximum pressure campaign in the first state is not substantial, the impact in the second state is much more influential. During the maximum pressure campaign, the average domestic price of barley was 0.24 % higher than the rest of the period. In other words, in this era and previous economic sanctions from 2012 to 2015, due to the higher cost of imports and excessive difficulty of purchasing from the international market, price management in the domestic market turned into a struggling issue for the government and the domestic market faced higher prices relative to the first state. Therefore, lifting the economic sanctions is an essential deriving force that could help to decrease and stabilize the barley price.

Finally, the Russian-Ukrainian conflict does not impose a statistically significant influence on domestic

Table 6. Regime properties for domestic barley price.

	Coefcient	Standard error
Transition probabilities		
P_{11}	0.966	0.019
P_{12}	0.033	0.019
P_{21}	0.039	0.02
P_{22}	0.960	0.02
Duration		
State 1	30.12	17.86
State 2	25.54	13.1

Source: Authors calculation.

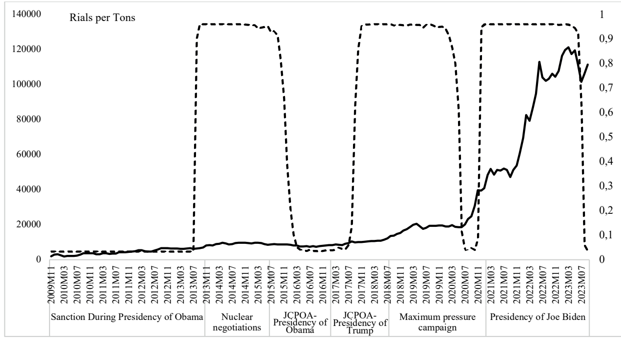


Figure 2. Transition probability of state 2 for domestic barley price. Source: Authors calculation.

barley prices in the state 1. Throughout the second state, the impact of armed conflict on domestic barley prices in Iran is positive and statistically significant; however, its impact is not substantial. This result is predictable because the dependency of Iran on Ukraine and Russia is relatively low (Zhang et al., 2023).

The properties of the two regimes are presented in Table 6, which shows that the transition probability for regime change is significantly low. The regime transition probability from regime 1 to 2 is 0.033, while the likelihood of regime changes from regime 2 to 1 is 0.039. Furthermore, regime 1 lasted longer than regime 2. The results indicated that regime 1 lasted 30 months, while the second stat continued for almost 25 months.

The transition probability of the first regime is depicted in Figure 2. It reveals that state 1 is prevalent from November 2009 to July 2013, and again, it becomes dominant from March 2016 to July 2017. The results indicate that the first regime prevails when the economic sanctions are lifted or not pursued by the US government.

4. CONCLUSION AND POLICY IMPLICATION

This study assessed the impact of main factors on barley prices, including global prices, exchange rates, domestic price volatility, and geopolitical conflict during the US maximum pressure campaign. For this aim, the Markov-switching approach has been applied to capture the possible non-linear behavior of the barley price from August 2009 to September 2023. The main results determined that a real effective exchange rate is a dominant deriving factor in domestic barley price formation in both regimes. Moreover, the barley price in the international market, domestic price volatility, and maximum pressure camping are driving forces of domestic barley prices. However, the contribution of global barley prices and the domestic price fluctuation has been diminished in the second state, while the influence of maximum-pressure camping has been exacerbated.

Based on the results, the government policy for stabilization of essential commodity prices through utilizing the preferential exchange rate. This policy should also weaken the weak connection between local and international markets. However, the study findings indicated that this policy does not mitigate the price variation in both regimes. Therefore, the government should have confined its intervention in the exchange market to the price stabilization proposed.

Moreover, since the increase in the domestic price volatility led to barley price intensification, the government should design a price volatility and mitigation system based on the facilitation of public procurement and management of governmental reserve to reduce the domestic price fluctuation by securing the supply of the barley in local markets in the case of demand surplus.

Finally, according to the results, the persistence of US economic sanctions amplified barley prices. Therefore, the Iranian government should pursue a political agenda to create a stable political condition and lift the economic sanctions by compromising their nuclear program. Based on the results, following this program should be considered the main priority for the government to mitigate a price upsurge.

This study faced some limitations that could be addressed to provide more precise results. First, there is a data limitation toward a monthly sanction index. In other words, calculating a more accurate sanction index could lead to a more precise assessment. Moreover, application of more flexible time series models such as state-space which estimates the yearly coefficients could lead to a more comprehensive assessment.

5. REFERENCES

Adekunle, W., and Ndukwe, C. I. (2018). The Impact of Exchange Rate Dynamics on Agricultural Output Performance in Nigeria. SSRN Electronic Journal, (87750). https://doi.org/10.2139/ssrn.3214757

Aliu, F., Kučera, J., & Hašková, S. (2023). Agricultural Commodities in the Context of the Russia-Ukraine War: Evidence from Corn, Wheat, Barley, and Sunflower Oil. Forecasting, 5(1), 351-373.

AWNRC. (2020). Food Security Report. Iran Chamber of commerce, industry, mine and agriculture, Tehran, Iran.

Baffes, J., Kshirsagar, V., and Mitchell, D. (2019). What Drives Local Food Prices? Evidence from the Tanzanian Maize Market. World Bank Economic Review, 33(1), 160–184. https://doi.org/10.1093/wber/lhx008

Bekkers, E., Brockmeier, M., Francois, J., and Yang, F. (2017). Local Food Prices and International Price Transmission. World Development, 96, 216–230. https://doi.org/10.1016/j.worlddev.2017.03.008

Bhagowalia, P., Headey, D., and Kadiyala, S. (2012). Agriculture, income, and nutrition linkages in India: insights from a nationally representative survey. IFPRI Discussion Papers, 31(28), 1–31. Retrieved from: https://ebrary.ifpri.org/digital/collection/p15738coll2/id/127051

Bollerslev, T. (1986). Generalized Autoregressive Conditional Heteroskedasticity. Econometrica, 31, 307–327.

Braha, K., Rajčániová, M., Qineti, A., Pokrivčák, J., and Lazorčáková, E. (2019). Evidence of spatial price transmission in the case of Kosovo. Agris On-Line Papers in Economics and Informatics, 11(1), 3–15. https://doi.org/10.7160/aol.2019.110101

Brown, M. E., and Kshirsagar, V. (2015). Weather and international price shocks on food prices in the developing world. Global Environmental Change, 35, 31–40. https://doi.org/10.1016/j.gloenvcha.2015.08.003

Caldara, D., & Iacoviello, M. (2022). Measuring geopolitical risk. American Economic Review, 112(4), 1194–1225.

Cedrez, C. B., Chamberlin, J., and Hijmans, R. J. (2020). Seasonal, annual, and spatial variation in cereal prices in Sub-Saharan Africa. Global Food Security, 26(June), 100438. https://doi.org/10.1016/j.gfs.2020.100438

Cinar, G. (2018). Price volatility transmission among cereal markets. The evidences for Turkey. New Medit, 17(3), 93–104. https://doi.org/10.30682/nm1803h

Clapp, J., Isakson, S. R., and Visser, O. (2017). The complex dynamics of agriculture as a financial asset: introduction to symposium. Agriculture and Human Values, 34(1), 179–183. https://doi.org/10.1007/s10460-016-9682-7

Daneshvar Kakhki, M., Farsi, M. M., Fakari, B., and Kojori, M. (2019). Volatility transmission of barley world price to the domestic market of Iran and the role of iran mercantile exchange; an application of BEKK model. New Medit, 18(3), 97–107. https://doi.org/10.30682/nm1903h

De la Torre-Torres, O. V., Aguilasocho-Montoya, D., Álvarez-García, J., and Simonetti, B. (2020). Using Markov-switching models with Markov chain Monte Carlo inference methods in agricultural commodities trading. Soft Computing, 24(18), 13823–13836. https://doi.org/10.1007/s00500-019-04629-5

Dinku, T., and Worku, G. (2022). Asymmetric GARCH models on price volatility of agricultural commodities. SN Business and Economics, 2(11). https://doi.org/10.1007/s43546-022-00355-7

Eissa, M. A., and Al Refai, H. (2019). Modelling the symmetric and asymmetric relationships between oil prices and those of corn, barley, and rapeseed oil. Resources Policy, 64(June), 101511. https://doi.org/10.1016/j.resourpol.2019.101511

Engle, R. F. (1982). Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation. Econometrica, 50(4), 987. https://doi.org/10.2307/1912773

Fakari, B., Farsi Aliabadi, M. M., Mahmoudi, H., and Kojouri, M. (2016). Volatility spillover and price shocks in Iran's meat market. Custos e Agronegocio, 12(2), 138–155.

Fakari, B., Farsi, M. M., and Kojouri, M. (2013). Determining fluctuations and cycles of corn price in Iran. Agricultural Economics (Czech Republic), 59(8), 373–380.

Farsi Aliabadi, M. M., Kakhky, M. D., Sabouni, M. S., Dourandish, A., and Amadeh, H. (2021). Food production diversity and diet diversification in rural and urban area of Iran. Journal of Agriculture and Environment for International Development, 115(1), 59–70. https://doi.org/10.12895/jaeid.20211.1252

Ghahremanzadeh, M., Faraji, S., & Pishbahar, E. (2020). The Transmission World Price and Exchange Rate to Domestic prices of Livestock's Major Imported Inputs in Iran. Agricultural Economics, 14(2), 23-52. https://doi.org/10.22034/iaes.2020.134731.1780

Ganneval, S. (2016). Spatial price transmission on agricultural commodity markets under different volatility regimes. Economic Modelling, 52, 173–185. https://doi.org/10.1016/j.econmod.2014.11.027

Guo, J., and Tanaka, T. (2019). Determinants of international price volatility transmissions: the role of self-

sufficiency rates in wheat-importing countries. Palgrave Communications, 5(1). https://doi.org/10.1057/s41599-019-0338-2
Hájek, J., and Horváth, R. (2016). Exchange Rate Pass-Through in an Emerging Market: The Case of the Czech Republic. Emerging Markets Finance and Trade, 52(11), 2624–2635. https://doi.org/10.1080/1540496X.2015.1090823
Hamilton, J. (2018). Regime Switching Models. In A Course on Statistics for Finance (pp. 199–214). Chapman and Hall/CRC. https://doi.org/10.1201/9781315373751-9
Hamilton, J. D. (1989). A New Approach to the Economic Analysis of Nonstationary Time Series and the Business Cycle. Econometrica, 57(2), 357. https://doi.org/10.2307/1912559
Hejazi, J., & Emamgholipour, S. (2022). The effects of the re-imposition of US sanctions on food security in Iran. International Journal of Health Policy and Management, 11(5), 651.
IMF (2023), International Monetary Fund Data Base. Available at: https://data.imf.org/regular.aspx?key=61545850
Kalligeris, E. N., Karagrigoriou, A., and Parpoula, C. (2021). An Advanced Markov Switching Approach for the Modelling of Consultation Rate Data †. Engineering Proceedings, 5(1), 1–5. https://doi.org/10.3390/engproc2021005002
Lanfranchi, M., Giannetto, C., Rotondo, F., Ivanova, M., and Dimitrova, V. (2019). Economic and social impacts of price volatility in the markets of agricultural products. Bulgarian Journal of Agricultural Science, 25(6), 1063–1068.
Layani, G., Bakhshoodeh, M., Aghabeygi, M., Kurstal, Y., & Viaggi, D. (2020). The impact of food price shocks on poverty and vulnerability of urban households in Iran. Bio-based and Applied Economics, 9(1), 109-125.
Liu, X. D., Pan, F., Yuan, L., & Chen, Y. W. (2019). The dependence structure between crude oil futures prices and Chinese agricultural commodity futures prices: Measurement based on Markov-switching GRG copula. Energy, 182, 999-1012.
Magrini, E., Bali, J., and Morales-opazo, C. (2017). Cereal price shocks and volatility in sub-Saharan Africa. what really matters for farmers' welfare?, 00, 1–11. https://doi.org/10.1111/agec.12369
Mehdizadeh Rayeni, M. J., Mohammadi, H., Ziaee, S., Ahmadpour, M., & Salarpour, M. (2022). Investigating the Relationship between Inflation and Price Fluctuations of Agricultural Products in Iran. Agricultural Economics Research, 14(3).
Mittal, S., and Hariharan, V. K. (2018). Price volatility trends and price transmission for major staples in India, 31(1), 65–74. https://doi.org/10.5958/0974-0279.2018.00006.X
Moghaddasi, R., Khaligh, P., And Ghalambaz, F. (2011). The Law of One Price in Iran Agricultural Products Market (Case Study: Barley, Rice and Cotton). Journal of Agricultural Extension and Education Research. 113 (4), 41-51.
Mohammadi, M., Mohammadi, H., and Fakari, B. (2016). The Impact of Macroeconomic Variables on the Volatility of Agricultural Prices in the Iran Mercantile Exchange (The Case of Barley). Agricultural Economics and Development, 24(3), 1-23. https://doi.org/10.30490/aead.2016.59041
Mosavi, S. H., Esmaeili, A. K., and Azhdari, S. (2014). Evaluating economic effects of exchange rate depreciation on the rice market in Iran. Journal of Agricultural Science and Technology, 16(4), 705–715.
Motamed, M. (2017). Developments in Iran's Agriculture Sector and Prospects for U.S. Trade. Economic Research Service/USDA: Washington, DC, USA. Retrieved from www.ers.usda.gov
Nasir, M. A., Nugroho, A. D., & Lakner, Z. (2022). Impact of the Russian–Ukrainian Conflict on Global Food Crops. Foods, 11(19), 2979.
Ott, H., and Ott, H. (2014). Volatility in Cereal Prices: Intra- Versus Inter-annual Volatility, 65(3), 557–578. https://doi.org/10.1111/1477-9552.12073
Pieters, H., and Swinnen, J. (2016). Trading-off volatility and distortions? Food policy during price spikes. Food Policy, 61, 27–39. https://doi.org/10.1016/j.foodpol.2016.01.004
Sadiq, S. M., Singh, P. I., and Ahmad, M. M. (2021). Does the Law of One Price (Lop) Holds in the International Barley Markets. Agricultural Social Economic Journal, 21(4), 251–266. https://doi.org/10.21776/ub.agrise.2020.021.4.1
Santeramo, F. G., and Lamonaca, E. (2019). On the drivers of global grain price volatility: An empirical investigation. Agricultural Economics (Czech Republic), 65(1), 31–42. https://doi.org/10.17221/76/2018-AGRICECON
Iqbal, M., Shahid, M., & Rashid, H. (2022). Impact of Money Supply and Exchange Rate on Agricultural Prices in Pakistan. Empirical Economic Review, 5(1), 01-26. https://doi.org/10.29145/eer.51.01
Sohag, K., Islam, M. M., Tomas Žiković, I., & Mansour, H. (2023). Food inflation and geopolitical risks: analyzing European regions amid the Russia-Ukraine war. British Food Journal, 125(7), 2368–2391.
Sokhanvar, A., and Bouri, E. (2022). Commodity price shocks related to the war in Ukraine and exchange rates of commodity exporters and importers. Borsa Istanbul Review, 23(1), 44–54. https://doi.org/10.1016/j.bir.2022.09.001

Statistical Center of Iran (2023). Price Index Database. Availabel at: https://amar.org.ir/english/SCI-News-Archive/articleType/CategoryView/categoryId/122/Price-indices.

Steen, M., Bergland, O., and Gjølberg, O. (2023). Climate Change and Grain Price Volatility: Empirical Evidence for Corn and Wheat 1971–2019. Commodities, 2(1), 1–12. https://doi.org/10.3390/commodities2010001

Tricase, C., Amicarelli, V., Lamonaca, E., and Leonardo Rana, R. (2018). Economic Analysis of the Barley Market and Related Uses. In Grasses as Food and Feed (Vol. 11, p. 13). IntechOpen. https://doi.org/10.5772/intechopen.78967

Uçak, H., Yelgen, E., & Arı, Y. (2022). The role of energy on the price volatility of fruits and vegetables: Evidence from Turkey. Bio-based and Applied Economics Journal, 11(1050-2022-786), 37-54.

Valera, H. G. A., and Lee, J. (2016). Do rice prices follow a random walk? Evidence from Markov switching unit root tests for Asian markets. Agricultural Economics (United Kingdom), 47(6), 683–695. https://doi.org/10.1111/agec.12265

Yosofi, H., & Moghadesi, R. (2013). World price transmission to domestic agricultural markets: Case of wheat, barley and rice. Agricultural Economics Research, 5(17), 81-99.

Zamanialaei, M., Brown, M. E., McCarty, J. L., & Fain, J. J. (2023). Weather or not? The role of international sanctions and climate on food prices in Iran. Frontiers in Sustainable Food Systems, 6, 998235.

Zhang, Z., Abdullah, M. J., Xu, G., Matsubae, K., & Zeng, X. (2023). Countries' vulnerability to food supply disruptions caused by the Russia–Ukraine war from a trade dependency perspective. Scientific Reports, 13(1), 16591.

BAE
Bio-based and Applied Economics

AIEAA
ASSOCIAZIONE ITALIANA DI ECONOMIA AGRARIA E APPLICATA

OPEN ACCESS

Citation: Esposti, R. (2024). Dating common commodity price and inflation shocks with alternative approaches. *Bio-based and Applied Economics* 13(2): 171-201. doi: 10.36253/bae-14060

Received: December 9, 2022
Accepted: November 2, 2023
Published: July 25, 2024

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Editor: Simone Cerroni

ORCID
RE: 0000-0002-1656-0331

Dating common commodity price and inflation shocks with alternative approaches

Roberto Esposti

Department of Economics and Social Sciences, Università Politecnica delle Marche, Ancona, Italy
E-mail r.esposti@staff.univpm.it

Abstract. This paper investigates the occurrence of common price shocks (co-exceedance) across different commodities. IMF monthly price series of 11 commodities are considered over the 1980-2021 period. The analysis considers two alternative stochastic processes. The first looks for common volatility clusters using individual GARCH models to detect whether and when respective clusters overlap. Through an appropriate battery of tests, the second alternative looks for a common Bubble Generating Process (BGP) by searching for individual explosive roots and then dating them to identify the possible overlaps and first movers. Evidence emerging about these shock generating processes is linked to the analogous behaviour of the US Consumer Price Index (CPI) to assess to what extent inflation shocks can be associated to the observed commodity price spikes. Results show that the detection of temporary bubbles and volatility clusters only partially agrees on the episodes of exuberance, on the first-moving commodities and on the involvement of the CPI. This provides helpful suggestions on the development of a real-time surveillance tool supporting policy intervention in periods of commodity price turbulence.

Keywords: commodity prices, price volatility, explosive roots, GARCH models.
JEL Codes: Q11, C32.

1. INTRODUCTION

The large and rapid surge of most commodity prices that started in 2021 and lasted for the whole of 2022 points to two stylised facts that have been repeatedly investigated in previous episodes of price spikes: commodity prices move together; the rise of commodity prices transmits, somehow, to the Consumer Price Index (CPI). The consequent inflation rate rush largely impacts economies and societies and usually induces a quite vigorous policy response (Ider et al., 2023). Nonetheless, the explanations of these price dynamics are still to be fully understood.

The literature on the common movement (or co-movement) of commodity prices is vast (Byrne et al., 2020). One limit of this literature is that it implicitly assumes that the communality of price dynamics has to be intended as the existence of a common Data Generation Process (DGP), usually represented

Firenze University Press | www.fupress.com/bae

via some variant of Vector Auto-Regression (VAR) or Vector Error Correction (VEC) models or through more sophisticated representation of the underlying common drivers (for instance, common latent factors) (Esposti, 2021). But this may contrast with empirical evidence that suggests substantially different fundamentals across very diverse commodities, thus questioning the presence of common real determinants to justify commonality. In general terms, most representations of the common DGP and of the consequent price transmission process (like the conventional Granger causality, for instance) may be too simplistic to capture the real underlying interdependence across commodities, if any, thus providing misleading evidence on the actual causal linkages.

However, a specific strand of the recent empirical literature stresses that a common DGP is not strictly needed for a common temporary behaviour to be observed (Zhao et al., 2021, p. 781; Mutascu et al., 2022). In particular, commonality may only occur within the periods of exuberance, also referred to as *co-exceedance*. When the price spike expires each series reverts to its own (possibly different) normal-time DGP. This hypothesis can be also transferred to the second stylised fact, that of the CPI response: for a transmission of shocks to the CPI to occur we do not need a common DGP with the commodity prices, but only some co-exceedance with them.

The presents paper aims to contribute to this body of studies by proposing an original methodological approach which then leads to a novel policy tool. The main originality of the approach consists in juxtaposing and combining two alternative stochastic processes generating co-exceedance. The first resides in the occurrence of common (but not interdependent, that is, multivariate) volatility clusters whose behaviour is here modelled through appropriate Generalised Auto-Regressive Conditional Heteroskedasticity (GARCH) models. The second consists in the occurrence of common bubbles (a common Bubble Generating Process, BGP), that is, temporary explosive roots within the individual series but whose timing largely corresponds across commodities. Individual price series of very diverse commodities are thus separately investigated in order to assess whether and when volatility clusters (first) and temporary explosive roots (second) are found. Although these methodological approaches have already been adopted in previous empirical studies (Otero and Baum, 2021; Phillips and Shi, 2020; Zhao et al., 2021), this paper proposes a combination of these techniques to assess the co-exceedance of commodity prices without relying on some arbitrary and unreliable common DGP.

Monthly series of 11 commodity prices and the respective price indexes released by the International Monetary Fund (IMF) over the 1980-2021 period are considered. Co-exceedance is assessed by confronting the occurrence of these events across series. If some overlapping is observed, it supports the existence of some contagion (or transmission) across prices. The sequence of the events across prices can finally suggest the direction of this possible contagion. The same analysis is then repeated on the US CPI.

The interest for this methodological approach eventually lies in its application to design a suitable policy tool. Instead of concentrating on complex and possibly misleading causation processes, the proposed empirical strategy aims to identify when periods of rapid price rises occur and assesses whether they are common across commodities. Therefore, it allows to develop a real-time surveillance tool guiding a prompt policy response in the right direction, in particular by distinguishing interventions that can be confined to the sectoral context from interventions that require an economy-wide spectrum of actions. In order to be easily interpretable also by non-technical users, this tool is aimed to transfer results into a sort of periodically updatable dashboard visualizing the critical information under investigation: if a bubble is occurring for a given commodity, when it started, whether other commodities are involved by the same bubble, who moved first and, finally, if and to what extend this price surge is also reflected in the CPI. Contributing to the definition of such a policy tool represents a further objective of the present study.

The rest of the paper is structured as follows. Section 3 overviews the recent empirical literature in the field while Section 3 presents the adopted dataset and the main stylised facts. Section 4 details the adopted methodological approach, the results of which are illustrated in section 5. In Section 6 these results are discussed and juxtaposed with the evidence emerging from more conventional methodologies about the investigation of commodity price dynamics. Section 7 draws some policy implications and concludes.

2. THE COMMON MOVEMENT OF COMMODITY PRICES: LITERATURE AND EVIDENCE

The paper by Wang and Tomek (2007) may represent the first study that explicitly and extensively discussed the sequence of empirical issues to be tackled in investigating the actual DGP of commodity prices. Though their main attention was on the stationarity properties of agricultural commodities, their conclusions can be extended to other commodities and properties of the unknown DGP. The main argument is that, due to their market fundamentals (on both the supply and the demand side), commodity prices are expected to be mean reverting, with the long-term mean value possibly moving along a deterministic trend. So, prices are expected to follow a stationary DGP around a drift or a trend.

The fact that in the empirical literature the presence of a unit root is only occasionally rejected has to be attributed to the characteristics of the respective tests and/or to their misspecification. In particular, other characteristics of a stationary DGP can make it similar to a unit-root process. One is that these prices often show long memory (that is, fractional integration) making it possible for a close-to-(but-lower-than)-one root to be confounded with a unit root. Another is the presence of a structural break that may shift the long-term value upward or downward and can itself generate a potential confusion as evidence of nonstationarity: the presence of a structural break within a stationary series may lead to accepting the presence of a unit root, thus wrongly concluding that the series is non-stationary (Baum, 2005; Glynn et al., 2007).

A consistent body of recent studies concentrates on several different stochastic processes to explain the complex (i.e., non-linear) commodity price dynamics and the possible underlying co-movement. They are, in particular, fractional integration and structural breaks. A recent example, though concerning stock market indices and not commodity prices is Caporale et al. (2020). Based on an approach originally proposed by Cuestas and Gil-Alana (2016), they argue that fractional integration is very much related to non-linearities.[1] The possibility of structural breaks is also considered since many studies argue that fractional integration might be artificially generated by the presence of breaks in the data that have not been taken into account. In fact, the presence of structural breaks within commodity price series was already considered by Wang and Tomek (2007).

However, it must be noticed that fractional integration and/or structural breaks can hardly explain the behaviour of commodity prices and, in particular, the abovementioned co-exceedance, that is, their recurrent episodes of temporary exuberance as also emerging by simple visual inspection (see next section). They remain interesting and possibly relevant processes in the investigation of individual DGP since they may significantly interfere with the investigation of temporary bubbles and/or GARCH effects. Therefore, although the approach here adopted considers other DGPs, the presence of structural breaks can not be excluded at least for some of these commodities (Esposti, 2021) and will be considered here for comparative purposes (see Section 6).

Concentrating on the stationarity properties these studies overlook another major characteristic of these price series that clearly emerges from a simple visual inspection: the presence of temporary exuberance. Therefore, their DGP is expected to also generate self-extinguishing periods of particularly high or low values. Most of the literature in the last 15 years has essentially focused on this issue also as a consequence of the 2007-2008 price spike and of the following turbulent period. A lot of theoretical and empirical research has tried to investigate the origins of these price nonlinearities, jumps and spikes, as well as to put forward testing procedures to assess their presence. We can summarize this research effort in three main directions and, then, in their possible combination.

The first strand of research explains the observed price spikes and jumps as the consequence of a temporary increase in their variability (or volatility). It is the formation of volatility clusters that eventually generates the observed highly irregular price dynamics. In most applications, this idea is implemented by specifying and estimating GARCH regression models possibly admitting asymmetric effects and non-stationary processes for the price level. See Li et al. (2017), Baur and Dimpfl (2018) and Esposti (2021), just to mention a few, for the application of different variants of GARCH modelling to commodity prices.

Within the second body of studies the origin of the episodes of price turbulence is the formation of temporary bubbles. Several tests have been originally proposed to detect temporary price bubbles within mean-reverting, thus stationary, processes (Gürkaynak, 2008). More recently, the presence of temporary bubbles has been admitted, and tested, within possibly non-stationary processes, that is, as temporary explosive roots emerging within unit-root processes (Phillips et al., 2011, 2015; Phillips and Shi, 2020). Gharib et al. (2021) and Zhao et al. (2021) have recently used this battery of tests to assess the co-exceedance of some commodity prices and to date the respective bubbles.

Co-existence of both processes is also possible. This is considered helpful for two complementary reasons. On the one hand, as already anticipated, it is always difficult to clearly distinguish between the outcome of these two processes (Gürkaynak 2008, pp. 182-183; Chang, 2012). On the other hand, none of the two alternative processes may totally capture all the features of the observed price dynamics. To reconcile these two alternative processes, Chang (2012) adopts an Autoregressive Jump-Intensity(ARJI)-GARCH model. Originally pro-

[1] Another interesting strand of empirical literature on commodity price dynamics, and strongly linked to non-linearities and fractional integration, consists in the so-called fractal approach (Cromwell et al., 2000).

posed by Chan and Maheu (2002), this model is in principle able to generate both temporary bubbles and volatility clusters within stationary processes.

The third strand of empirical research in the field differs from the conventional time-series approaches as it is grounded on the spectral analysis and in time–frequency approaches. For the evolution of market prices, wavelet analysis has emerged as a useful and powerful tool in assessing price co-movement cycles. Without resorting on any theoretical causation (price transmission) process, it allows to explore how the series of prices are related at different frequencies admitting non-linearities like structural breaks.[2] Mutascu et al. (2022) provide a valuable example of this kind of approach by investigating the co-movements of gasoline and diesel prices in different countries at different frequencies. Though this approach is relatively new, interesting and promising, it is still based on the assumption of a permanent interdependence between prices although flexible and not-linear. In the present study, as anticipated, we do not want to admit any persistent co-movement but only co-exceedance, therefore prices moving together only in specific periods of price spikes. Nonetheless, the combination of the co-exceedance analysis here proposed with wavelet analysis can open interesting developments for future research in this area.

Here, the aim is to investigate the commodity price dynamics following the first two relative recent strands of research by pointing to commodity price co-exceedance rather than co-movement. In particular, unlike Chang (2012) and Zhao et al. (2021) the objective is not to estimate the parameters of the actual DGP but to date the episodes of price turbulence by confronting, in this respect, two competing processes: GARCH within stationary processes (*volatility clusters*) and temporary explosive roots within non-stationary processes (*bubbles*). Moreover, unlike Zhao et al. (2021) here we do not adopt Granger causality testing to assess the direction of the possible transmission of the price shocks across commodities.[3] By dating these periods individually, we provide evidence on this transmission by solely juxtaposing the timing of the individual episodes.

This is done not only on commodity prices and price indexes but also on the CPI series. While the empirical literature on the commodity price properties and behaviour is vast and follows the abovementioned directions, the investigation of the CPI dynamics (and its growth rate, the inflation rate) mostly follows other directions. It mainly concentrates on the common movement and possible interdependence with other macroeconomic variables and is only occasionally connected to commodity prices (Garzón and Hierro, 2022; Ider et al., 2023). GARCH effects possibly occurring in the CPI or inflation rate series has been extensively analysed (Engle, 1982), but we are not aware of studies assessing the presence of temporary bubbles within these series. In fact, visual inspection seems to suggest quite different properties of CPI compared to commodity prices (see next section). Nonetheless, if a transmission from commodity prices to CPI is expected, especially in periods of price turbulence, this should imply some form of co-exceedance between these series.

But there is a final original aspect of the present contribution with respect to the recent literature in the field. It concerns the policy implications of the proposed empirical approach. In previous studies either these implications are overlooked or they concentrate on the possible effect of policy interventions on the nature and scope of commodity price co-movement or co-exceedance like, for instance, the fuel tax system (Mutascu et al., 2022) or import tariffs (Esposti and Listorti, 2018). If the main objective of a policy in this context is to minimize the negative impact of a generalized rise of commodity prices, knowing the possible underlying causation and transmission process, that is the structural linkages generating co-movement, might not be so critical. What seems important is rather a quick understanding that a price "bubble" is forming and whether or not it is just sectoral (so it involves a limited number of commodities) or it is generalized across all markets, that is, it is a co-exceedence. Sectoral interventions to neutralize a momentary price surge are present in many contexts and are usually rapidly activated (in the case of agricultural commodities, for instance, the agricultural market-crisis interventions represent an interesting example (FAO et al., 2011)). When occurring on first-moving prices, these prompt sectoral responses may help to prevent a generalized "bubble". Understanding if and when this latter is, in fact, occurring then becomes critical to promptly activate system-wide actions, particularly intended to prevent or slow-down downstream impact on inflation rate surges (Ider et al., 2023). This real-time surveillance tool able to provide such an early warning, as well as the generality and the first movers of the "bubble", seems to be particularly helpful for a prompt policy response.

[2] We wish to thank an anonymous reviewer for helpful suggestions on this aspect.

[3] Granger causality tests imply a common linear DGP across series (VAR or VEC models) (Zhao et al., 2021, p. 783). But both commonality and linearity may not hold in the present case. Nonetheless, for the sake of comparison and robustness check of results, in Section 6 we will present Granger causality tests.

3. PRICE SERIES UNDER SCRUTINY

The present analysis concerns the price of a selection of 11 commodities belonging to three different categories: 4 agriculture commodities (corn, wheat, soybean, beef); 3 energy commodities (crude oil, natural gas, coal); 4 metals (aluminium, copper, zinc; nickel).[4] All price series are taken from the IMF commodity price dataset.[5] All prices are monthly and cover the period January 1980 (1980M1)-December 2021(2021M12) (504 observations) with the only exception of natural gas whose series starts in 1985M1 (444 observations).

Together with individual commodity prices, the IMF dataset also contains aggregate price indexes for groups of commodities. Here, three monthly price indexes are considered: food price index (FoodInd) covering the period 1991M1-2021M12; metals price index (MetInd) covering the period 1980M1-2021M12; fuel (energy) index (EneInd) covering the period 1992M1-2021M12. Annex 1 provides details about which product quality these prices refer to, where they have been collected and on which aggregates respective indexes have been defined. Table A1 also reports the respective descriptive statistics which include the conventional distributional indices suggesting that commodity prices depart from the normal distribution mostly for a longer right tail depending on the exceptionally high prices observed during temporary bubbles.

The dynamics of commodity prices is investigated in combination with the evolution of the overall consumer price index (CPI). Unfortunately, no worldwide (or global) CPI is available. Moreover, many available CPI are usually collected and released at a quarterly or yearly basis. Here, the US monthly CPI series is used (see Annex 1 for more details).[6] This series seems suitable in the present analysis not only for the concordant frequency, but also because the US still represents the largest economy worldwide, so any impact of the global commodity prices on inflation can be consistently assessed on this series. It must also be noticed that, as detailed in Annex 1, several price series concern US markets and, in any case, all prices are expressed in US $. Therefore, using the US CPI does not incur the risk of downscaling (if not neutralizing) the transmission of commodity price shocks to the CPI due to the exchange rate adjustment (Garzón and Hierro, 2022).

Unlike many previous studies (Esposti, 2021), commodity prices, as well the three price indexes, are not deflated. As here we want to investigate the possible impact of commodity price spikes on the CPI, it does not seem appropriate to purge inflation from these series. The same strategy is followed for the possible presence of seasonality: no seasonal adjustment is performed on price series and indexes. The logic behind this choice is twofold. On the one hand, we prefer to analyse the price series that economic agents really confront with. On the other hand, as stressed by Wang and Tomek (2007) and Corradi and Swanson (2006), any data transformation has to be taken with care as it could introduce artefacts within the series under investigation.

However, we consider as appropriate a data transformation that is supported by the theory (Corradi and Swanson, 2006, p. 222). This is the case of the logarithmic transformation of the price levels. This transformation is largely used in empirical literature (Listorti and Esposti, 2012; Esposti and Listorti, 2013) and has two main motivations. First of all, price logarithms are more likely to show a normal distribution than price levels, and normality is usually required by the estimation and inference approaches. In other words, the log-normal statistical distribution of price levels has to be considered as a main regular feature of these series (Listorti and Esposti, 2012; Esposti and Listorti, 2013).

Secondly, the logarithmic transformation finds a robust theoretical justification in deriving the commodity price dynamics as Geometric Brownian Motions (GBM) (Diba and Grossman, 1988; Gürkaynak, 2008; Su et al., 2017). This tradition also includes the idea of "rational bubbles", that is, periods of price exuberance entirely justified by agent's expectations about commodity fundamentals (Diba and Grossman, 1988). Empirically, this hypothesis implies that price logarithms might take the form of mean reverting processes (due to market fundamentals) plus a random walk, a mean-reverting non-constant volatility (GARCH) and, possibly, temporary explosive roots.[7] According to Ibrahim et al. (2021), a GBM can generate a stochastic process that assumes normally distributed price level growth rates (therefore, difference in the logarithms) while admitting both unit-root (with drift and/or deterministic trend) and GARCH effects (volatility clusters).[8] However, these recent studies

[4] Selected commodities are the most important worldwide (in terms of value) within the respective categories. In fact, nickel is the fifth in the list of metals after lead. But for this latter a sufficiently long series is not available.

[5] These price series are proprietary and can not be made available within the paper's material. However, they can be freely downloaded at https://data.imf.org/?sk=471DDDF8-D8A7-499A-81BA-5B332C01F8B9 or requested at https://www.imf.org/en/Research/commodity-prices.

[6] This data can be freely downloaded from https://fred.stlouisfed.org/series/CPIAUCSL.

[7] Actually, Diba and Grossman (1988) exclude that, within this logic, a rational bubble can actually start: if it is observed it must always have existed.

[8] See also Agustini et al. (2018) for a similar derivation.

do not admit temporary bubbles. Taking into account pros and cons of the logarithmic transformation (Corradi and Swanson, 2006; Wang and Tomek, 2007), the present paper considers both the price levels and the logarithm of price levels and in parallel repeats the analysis for these two cases in order to assess which results are robust across the transformation.

Annex 2 displays the time evolution of the three aggregate price indexes (Figure A1), the 11 individual commodity prices (Figures A2-A4) and the logarithms of these individual prices (Figures A5-A7) over the 1980M1-2021M12 period.[9] Visual inspection points to some general characteristics of the price dynamics. Within each group, commodity prices seem to show some common movements: periods of exuberance as well as collapses substantially correspond across different commodities. This is only partially confirmed across groups: metals and agricultural commodities tend to share the same periods of rise and fall, while energy commodity prices seem more stable and less volatile at least until the very last years of the period under consideration. However, if aggregate price indexes instead of individual series are considered, it emerges that the three series largely overlap with a substantial correspondence of positive and negative spikes. What is common across commodities is also that price turbulence seems to sharply increase in the second half of the period under consideration and, in particular, from 2005 onwards.

From this simple visual inspection, therefore, the hypothesis of common movement seems largely supported. For all commodities, periods of temporary exuberance are recurrently observed. During these periods, prices rapidly increase and then rapidly collapse to a level that does not differ much from the pre-exuberance level. Therefore, despite these “bubbles”, prices still seem to behave like mean-reverting processes. This does not exclude changes in the long-term mean level or a long-term trend in this respect (Esposti, 2021). But these changes or trends seem mild and are overshadowed by the large short-term instability. As could be expected, the logarithmic transformation does not change the general behaviour of the series. Qualitatively, price levels and their logarithms are similar even though the latter are obviously smoother and this seems particularly evident for the energy commodity prices.

At the same time, major differences emerge between commodity price series and the CPI series. Figure A8 (Annex 2) reports the CPI, its monthly growth rate (i.e., the inflation rate) together with the oil price which arguably is one of its major drivers, but it is also one of the most stable commodity prices. The difference is evident. Oil price seems to follow a mean reverting process possibly with an increase of volatility in the second part of the period and an upward shift of the long-term mean value. CPI is much more stable, also in the second half of the period, and apparently moves along a deterministic trend. It follows that the inflation rate seems to behave like a mean-reverting process around an almost-zero long-term value with a limited, though appreciable, increase in the variability in the second half of the period.

This purely visual inspection gives rise to the two key research questions underlying the present study. On the one hand, commodity prices seem to move together at least during periods of turbulence, but this would suggest a common stochastic process whose properties, however, are not self-evident. Most price series show some characteristics of mean-reverting processes, and this would indicate they are stationary processes around drifts or trends. But the large and quick shocks, though temporary, do not seem consistent with this kind of processes. There should be some other underlying stochastic process, that may differ across prices but still admits their common movement at least in the periods of turbulence.

On the other hand, the research challenge about the linkage between commodity prices and the CPI is quite the opposite. They apparently behave as very different stochastic processes, so commonality should be excluded. Nonetheless, strong economic arguments, as well as an abundant empirical evidence (Garzón and Hierro, 2022), suggest that a common movement of many critical commodity prices has to be transferred, somehow, to the CPI.

4. THE METHODOLOGICAL APPROACH

The common theoretical framework of the investigation of commodity price dynamics consists in price formation mechanisms (or equations), that is, reduced-form models expressing the respective underlying market equilibrium.[10] Price formation equations represent the dynamic stochastic process as a mean-reverting or non-stationary process eventually generating the price level and volatility. These reduced form models have the further advantage of allowing a compact representation of cross-commodity price dynamics in the form of multiple

[9] The logarithmic transformation is not considered here for the price indexes and CPI. It would rather require a different aggregation of the elementary prices into the index and this would simply generate another kind of index possibly introducing a further artefact.

[10] Fackler and Goodwin (2001) provide a common template based on linear excess demand functions embracing all dynamic regression models from which an estimable reduced-form model can eventually be derived.

simultaneous equation models that may explain both co-movement and co-exceedance.

The theoretical justification of these cross-commodity price transmission mechanisms, however, is not univocal. The prevalent explanation is that also very different commodities (for instance oil and corn) may display interdependence in the respective fundamentals (i.e., demand and supply). For instance, on the supply side, one commodity (e.g., oil) may enter as an input (thus, a cost) in the production process or supply chain of another commodity (e.g., corn and, consequently, beef). On the demand side, consumption of one commodity may be directly (through substitution effect) or indirectly (through income effect) affected by the price of another commodity (Dawson et al., 2006; Listorti and Esposti, 2012; Esposti and Listorti, 2013). Sometimes, however, this interdependence through the fundamentals can be so indirect and remote that it seems more reasonable to provide another theoretical justification of price co-movement and co-exceedance: though prices are not interdependent, they still all respond to the same underlying (often latent) common factors (Stigler, 2011; Byrne et al., 2020; Esposti, 2021).

The research question underlying the present study, however, comes before these theoretical representations of price interdependence, that is nature and forms of price co-movement and co-exceedance. It rather looks for empirical support on the evidence of co-exceedance, its possible temporary nature and its dating. Therefore, we work on univariate models and not on multivariate models.

On these premises, consider N commodities whose price is observed over T time periods (months in the present case). On the basis of rational agent's expectation or efficient markets theory (Zhao et al., 2021), assume that for any i-th commodity there exists an unobserved fundamental price depending on the real market drivers (supply, demand, storage, expectations). The natural constraints applying to these drivers should make this market fundamental price nonexplosive. The actual (i.e. observed) price moves around this fundamental level but it usually deviates from it according to some underlying stochastic DGP expressed by the following univariate price formation equation:

$$p_{it} = \alpha_i + \delta_i t + b_i p_{it-1} + u_{it},\ \forall i \in N,\ \forall t \in T \quad S<T \tag{1}$$

where p_{it} is the i-th commodity price (or the logarithm of price) at time t; α_i expresses the drift while δ_i the deterministic trend coefficient. α_i, δ_i, b_i thus are commodity specific unknown parameters to be estimated. α_i and δ_i indicate the long-term fundamental price level or the long-term deterministic trend, respectively, to which the actual price is expected to revert.

The error term u_{it} is usually assumed to be normally, independently and identically distributed, that is $u_{it} \sim NID(0,\sigma^2)$. However, as autocorrelation in these disturbance terms is very likely to occur, (1) can be augmented to account for a transient dynamics:

$$\Delta p_{it} = \alpha_i + \delta_i t + \beta_i p_{it-1} + \sum_{s=1}^{S} \theta_{is} \Delta p_{it-s} + \varepsilon_{it},\ \forall i \in N,\ \forall t \in T\ \ S<T \tag{2}$$

where $\beta_i = (\beta_i\text{-}1)$ and θ_{is} are further commodity specific unknown parameters to be estimated. The error term is now correctly assumed to be $\varepsilon_{it} \sim NID(0,\sigma^2)$. (2) is the typical Adjusted Dickey-Fuller (ADF) regression and may admit different DGPs depending on the value of β_i. In particular, the price series is stationary, possibly around a drift (α_i) or a trend ($\beta_i t$), whenever $\beta_i < 0$. If $\beta_i = 0$, the price series contains a unit root and it thus follows a non-stationary process (a random walk) possibly with a drift (α_i) or a trend ($\beta_i t$). Finally, whenever $\beta_i > 0$, the price series has an explosive root implying a permanent and progressive departure from the fundamental price level unless it is temporary (a "bubble"). In practice, such process would contradict the actual existence of a fundamental price level.

Based on (2), distinct DGPs can be considered to represent the observed deviation of prices from the alleged fundamental level. Firstly, a Generalized Autoregressive Conditional Heteroskedasticity effect on ε_{it} can be included to capture the presence and persistence of volatility clusters. This is obtained by reformulating (2) as follows (GARCH(p,q)) regression model):

$$\begin{aligned} \Delta p_{it} &= \alpha_i + \delta_i t + \beta_i p_{it-1} + \sum_{s=1}^{S} \theta_{is} \Delta p_{it-s} + \varepsilon_{it} \\ \sigma_{it}^2 &= \gamma_i + \sum_{p=1}^{P} \rho_{ip} \varepsilon_{it-p}^2 \varepsilon_{it} + \sum_{q=1}^{Q} \omega_{iq} \sigma_{it-q}^2,\ \forall i \in N, \forall t \in T \quad S,P,Q<T \end{aligned} \tag{3}$$

where $\varepsilon_{it} = \sigma_{it} z_{it}$ with $z_{it} \sim NID(0,1)$. σ_{it}^2 is the it-h commodity price error term variance at time t, and ρ_{ip} and ω_{iq} are further commodity specific unknown parameters to be estimated. Together, parameters ρ_{ip} (also called ARCH terms) and ω_{iq} (called GARCH terms) express the overall degree of persistence of volatility. It is usually assumed that $\rho_{ip} + \omega_{iq} < 1$ (with $p=q$), indicating that volatility is mean reverting. Otherwise, we would be faced with a persistent volatility, i.e., volatility behaving as a random walk (or non-stationary) process (Engle, 1982; Agustini et al., 2018).[11] Once the GARCH model parameters have been estimated on the basis of the observed series, it is possible to assess whether and when volatility clusters occur. To do this, in-sample predictions of variance (i.e., $\hat{\sigma}^2_{1t}$) are generated. Then, on the basis of some pre-determined threshold (see below) clusters are found in those periods when this limit is exceeded.[12]

But a GARCH process is just one of the possible DGPs consistent with the observed irregular commodity price dynamics. As stressed by Engle (1982), a GARCH regression like (3) can be just an approximation to a more complex regression with non-ARCH disturbances. So, the GARCH specification might be picking up the effect of some relevant omissions from the estimated model. For this reason, we want here to make (3) compete with a second, and alternative, stochastic process generating a similar price behaviour. It consists of a DGP admitting temporary (or periodically collapsing) bubbles in the price levels. This DGP can be represented as a variant of the ADF regression (2) as follows:

$$\Delta p_{it} = \alpha_i^{r_1,r_2} + \delta_i t + \beta_i^{r_1,r_2} p_{it\text{-}1} + \sum_{s=1}^{S} \theta_{is}^{r_1,r_2} \Delta p_{it\text{-}s} + \varepsilon_{it},\ \forall i \in N, \quad \forall t \in Tr_1,\ r_2 \in T \quad S > T \tag{4}$$

where r_1 and r_2 denote the starting and ending points, respectively, of the possible temporary bubble. r_1 and r_2 are expressed as fractions of T so that $r_2 = r_1 + r_W$, where r_W is the window size of the regression, also expressed as a fraction of T. The number of observations to estimate (4) is $T_W = [Tr_W]$, where $[\cdot]$ is the floor function which gives the integer part of the argument (Otero and Baum, 2021). For series showing temporary bubbles we should observe explosive roots for some sub-periods, that is, some $[r_1,r_2]$ interval. This can be assessed through tests where the null hypothesis is $H_0{:}\beta_i^{r_1,r_2} = 0$, implying that the series shows a unit root, against the alternative hypothesis $H_0{:}\beta_i^{r_1,r_2} > 0$, implying that the series shows an explosive root in the $[r_1,r_2]$ interval.

A key contribution to a consistent formulation and implementation of this kind of tests was originally made by Phillips et al. (2011), then improved by Phillips et al. (2015) and Phillips and Shi (2020). The basic version of the test is the right-tailed ADF statistic based on the full range of observations, $r_1 = 0$ and $r_2 = 1$ (i.e., $r_W = 1$), denoted ADF_0^1. As it applies to the whole period of observations, this statistic may fail in detect short-time temporary bubbles. Therefore, a second statistic is based on the supremum t-statistic (SADF) that results from a forward recursive estimation of (4):

$$SADF(r_0) = sup_{r_2 \in [r_0,1]} ADF_0^{r_2} \tag{5}$$

Also this statistic may fail in the case of multiple temporary bubbles within the series. A third statistic can be thus computed. It is the generalised supremum ADF (GSADF) test:

$$GSADF(r_0) = sup_{r_2 \in [r_0,1], r_1 \in [0, r_2 - r_0]} ADF_{r_1}^{r_2} \tag{6}$$

Based on these statistics, it is firstly possible to asses if one or more temporary bubbles occur. Secondly, a backward testing procedure (backward SADF, or BSADF, statistics) allows dating these bubbles over the period T (Phillips et al., 2011; 2015). For any particular observation, i.e. the i-th commodity observed at time r_2, it is possible to test whether it belongs to a phase of explosive behaviour by performing a SADF test on a sample sequence where the endpoint is fixed at time r_2, and expands backwards to the starting point, r_1, which varies between 0 and $(r_2 - r_0)$. This backward SADF statistic is defined as:

$$BSADF_{r_2}(r_0) = sup_{r_1 \in [0, r_2 - r_0]} ADF_{r_1}^{r_2} \tag{7}$$

A further refinement of these tests has been recently proposed by Phillips and Shi (2020) and takes into account both the presence of heteroskedasticity and the multiplicity issue in recursive testing. They thus recommend a wild bootstrap approach to compute the critical values of the abovementioned tests.[13]

The methodological approach followed here can thus be summarised as follows. Firstly, we look for the stochastic properties of the individual commodity price series and the CPI. In particular, the presence of a unit-root (with or without a drift or a trend) and of ARCH effects is investigated. Secondly, on the basis of the first-step evidence, GARCH effects are considered as the possible explanation of the observed periods of price turbulence. GARCH regression models like (3) are estimated on individual series and in-sample volatility predictions are generated to assess and date the volatility clusters.

[11] This is also called Integrated GARCH (IGARCH) process/model (Campbell et al., 1996; Chan, 2010).

[12] Although their validity in generating reliable predictions is largely questioned, ARCH/GARCH models are usually quite successful in generating in-sample projections (Taleb, 2009).

[13] One limit of these tests is that they do not allow breaks in levels or time trends. As discussed, neither a trend nor a structural break can explain by itself the observed irregular price behaviour. However, they can not be excluded at least from some commodities (see Table 1) and might affect both the statistics and the critical values of these explosive root tests.

Thirdly, as an alternative to GARCH processes, we consider the formation of temporary bubbles as expressed by (4), therefore as a momentary departure from the fundamental process either stationary or non-stationary. ADF_0^1, SADF and GSADF tests are performed on individual series and the temporary bubbles, if any, are consequently dated by performing the BSADF test. Finally, the beginning and the end of volatility clusters and of temporary bubbles are confronted both across the two alternative processes and among commodities (and CPI) in order to assess similarities and differences, as well as the presence of possible contagion effects. Thus the analysis of co-exceedance simply consists in seeing whether volatility clusters or bubbles are common (i.e., overlap) or not. In case of a positive answer, it is then legitimate to ask, and to assess, whether a contagion effect can be deduced, that is, which series (i.e. price) moves first possibly driving the movement of the others.

Clearly, this investigation can not be confused with a formal causality assessment or testing. Usual time-series causality assessment in a multivariate context is performed via Granger causality testing. This latter, however, assumes a linear relationship across commodities and does not seem consistent with the observed stochastic properties of these series and bubble formation. In this respect, some recent developments in the field seem promising for future research (Shahzad et al., 2021; Esposti, 2022). It is worth stressing, however, that assessing causality is not so essential for the main policy implication of interest here. Investigating which commodities show a bubble formation earlier than others remains useful to build that real-time warning policy tool mentioned in previous sections.

5. RESULTS[14]

5.1. Stochastic properties of the series

Table 1 reports the battery of unit root tests and of the ARCH tests on (2) for all series under investigation. In the case of price indexes, CPI included, it emerges that all series are stationary. The selected specification[15] includes a drift in the case of the three commodity price indexes and a trend in the case of CPI. At the same, all indexes here show an ARCH effect except FoodInd. Consequently, all indexes behave as mean-reverting processes (with the mean moving along a deterministic trend in the case of CPI) possibly with volatility clustering.

Table 1. Unit root (ADF) and conditional heteroskedasticity (ARCH) tests on commodity price indexes and commodity prices (1980M1-2021M12)[a].

Series	ADF[b] (w/o drift&trend)	ADF (with drift)	ADF (with trend)	ARCH[c]
Price indexes				
FoodInd[d]	0.475	-1.224†	-2.439	0.126
MetInd	-0.088	-1.404†	-2.721	82.74*
EneInd[e]	0.150	-0.915†	-3.138	106.9*
CPI	6.988	0.539	-2.492†	72.91*
Price levels				
Oil	-0.502	-1.594†	-2.906	92.63*
Coal	-0.327	-1.599†	-3.415	160.9*
Gas[f]	0.581	-0.409†	-2.249	228.6*
Aluminium	-0.416	-3.063*	-4.010†*	65.84*
Copper	0.522	-0.621	-2.487†	112.8*
Zinc	-0.229	-2.023†*	-3.804*	106.9*
Nickel	-1.041	-2.628†*	-3.368	84.09*
Wheat	-0.375	-2.816†*	-3.349	108.9*
Corn	-0.214	-1.872†*	-2.891	29.86*
Soy	-0.322	-2.089†*	-3.288	67.44*
Beef	1.004	0.049	-1.739†	64.76*
Logarithm of price levels				
Oil	-1.199	-1.202†	-2.631	78.04*
Coal	0.429	-1.501†	-2.919	79.51*
Gas[f]	-1.737	-1.445†	-2.647	68.6*
Aluminium	0.178	-3.169†*	-4.322*	65.86*
Copper	0.784	-0.858†	-2.710	40.29*
Zinc	0.693	-1.827†*	-3.478*	19.18
Nickel	0.354	-2.008†*	-3.102	19.62
Wheat	0.252	-2.410†	-3.045	28.32*
Corn	0.315	-1.755†*	-2.855	7.38
Soy	0.212	-2.032†*	-3.243	24.67*
Beef	0.887	-0.167†	-1.839	42.35*

*Statistically significant at 5% confidence level.
† Selected specification according to Enders (1995, p. 256-260).
[a] The test specification in terms of lags included has been selected case by case on the basis of the AIC.
[b] 5% Critical Value of the three ADF test specifications, respectively: -1.95; -1.65; -3.42.
[c] Lagrange Multiplier (LM) test performed on the residuals of the ADF unit-root test equations; 5% Critical Value: 21.03.
[d] 1991M1-2021M12.
[e] 1992M1-2021M12.
[f] 1985M1-2021M12.

[14] All testing and estimation procedures have been performed with software STATA 17. In particular: GARCH models have been estimated using the command Arch with arch(1) garch(1) specification; explosive roots have been tested using the Radf command; the structural break tests have been performed using commands Zandrews and Clem; pairwise Granger causality tests have been performed by using, the Var and Vargranger commands.
[15] The best specification has been selected following Enders (1995, p. 256-260).

Regarding the individual commodity price series, however, a differentiated picture emerges across the commodity groups. If the levels are considered, energy commodities are all stationary around a drift. Metals, on the contrary, show non-stationarity around a drift in the case of zinc and nickel, non-stationarity around a trend in the case of aluminium and stationarity in the case of copper. Finally, all agricultural commodities, except for beef, are non-stationary around a drift while beef is stationary around a deterministic trend. Despite these difference, all commodity prices show an ARCH effect.

Interestingly enough, the logarithmic transformation changes the evidence emerging from the tests only for four commodities and only in one case (wheat) does this change concern stationarity properties. aluminium remains non-stationarity but now around a drift. Also copper and beef downscale from a trend to a drift while maintaining stationarity. Wheat shows the most significant change passing from non-stationarity around a drift to a stationarity around a drift. Thus, unlike the respective price level, the logarithm of the wheat price seems to behave like a mean-reverting process.

The key point, here, is that while visual inspection of both price indexes and price series would indicate some common movement, tests indicate that such commonality may occur for price indexes but not for individual prices where four different DGPs are observed, and this happens also within the same commodity group. This makes the hypothesis of common movement hardly tenable, at least over the whole time period. At the same time, however, visual inspection also reveals the presence of common periods of exuberance that are not necessarily compatible with the DGPs emerging from tests. The limited reliability of the DGPs emerging from the tests when compared to the actual price dynamics is confirmed by generating in-sample predictions from the estimated ADF regressions.

Figure 1 compares these predictions with the real series for two cases that should express different DGPs: a stationary series around a drift (mean reverting) (oil)

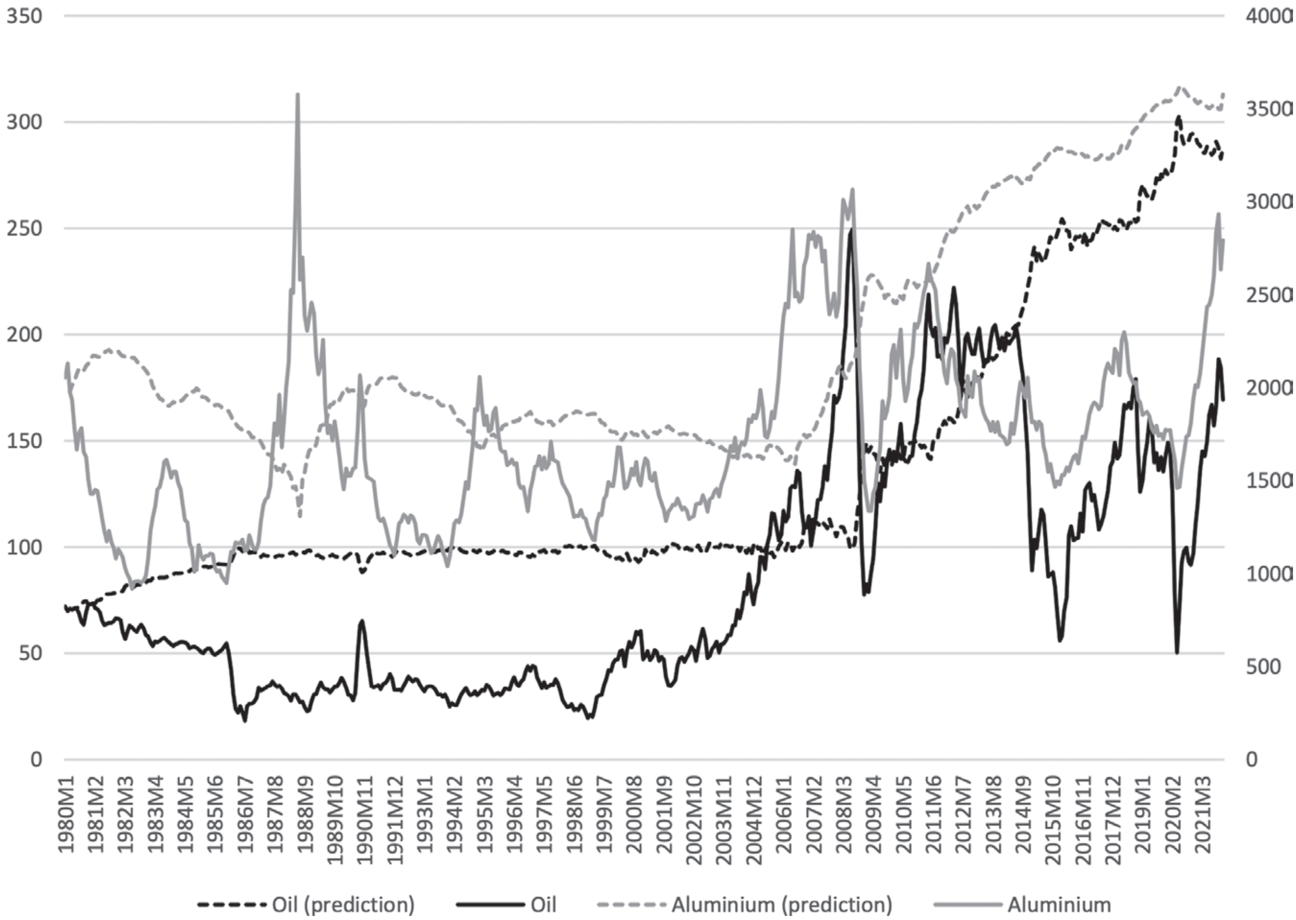


Figure 1. Oil (left scale) and Aluminium (right scale) prices: observed series and in-sample predicted series from respective ADF model estimation (1980M1-2021M12) (see Annex 1 for units of measure).

and a non-stationary series around a trend (aluminium). The two predicted series are quite similar, despite the different DGPs, and, above all, in both cases these predictions largely diverge from the actual series especially in the last third of the observed period. Evidently, there is something more in the stochastic process generating these series and this has to do more with temporary effects than with constant properties of the series. As the ARCH test is concordant across all series (except for FoodInd), the presence of volatility clusters can be a serious candidate to explain these temporary processes. But also temporary explosive roots (bubbles) could be considered as they are compatible with both stationary and non-stationary series over the whole period (Diba and Grossman 1988, p. 529).

5.2. Volatility clusters

Table 2 reports the estimates of parameters ρ and ω of the GARCH regression model (3) (with a GARCH(1,1) specification) for the different series in both price levels and logarithms. Two main facts emerge. First of all, with the only exception of FoodInd, in all series both estimated ρ and ω are statistically significant (Corn is the only case where ρ is not statistically different from 0). This confirms what was already obtained with ARCH tests presented in Table 2: volatility clusters occur in all series except for FoodInd. Secondly, many series violate the assumption of temporary clusters: for the price indexes EneInd and CPI, and price levels of natural gas, aluminium, zinc, wheat, corn, beef, we can not reject the hypothesis of $\rho+\omega=1$. Therefore, in these cases volatility follows a non-stationary process thus making clusters permanent rather than temporary as expected. Logarithms of prices partially confirm this evidence but some differences are worth noticing: non-stationary volatility is observed also for oil and nickel while it is now excluded for aluminium, zinc and beef.

Contradictory evidence emerges about the reliability of these GARCH processes as generators of the observed price dynamics. On the one hand, the existence of volatility clusters is consistent with the observed large variability, or instability, of the commodity prices in specific periods of time. On the other hand, however, in several cases these processes support permanent volatility shocks thus becoming less compatible with the observed temporary episodes of turbulence. As discussed, once estimated, standard error in-sample predictions for these GARCH models can be generated. Figure 2 shows these predictions for the three price indexes and Figures 3a-3b for the individual price levels and logarithms, respectively. Figure A9 (panel a)) reports the same predictions for the CPI and its growth rate (i.e., inflation rate).

Table 2. GARCH(1,1) model estimation and persistency test on commodity price indexes and commodity prices (1980M1-2021M12) (estimated standard errors in parenthesis)[a].

Series	ρ		Ω		Test $\rho+\omega=1$ ($\chi^2(1)$)
Price indexes					
FoodInd[b]	0.036	(0.049)	-0.171	(0.717)	3.96*
MetInd	0.247	(0.049)*	0.675	(0.032)*	4.24*
EneInd[c]	0.373	(0.081)*	0.641	(0.058)*	0.16
CPI	0.116	(0.022)*	0.879	(0.021)*	0.22
Price levels					
Oil	0.343	(0.041)*	0.726	(0.031)*	10.4*
Coal	0.494	(0.062)*	0.664	(0.026)*	13.4*
Gas[d]	0.304	(0.051)*	0.625	(0.044)*	3.52
Aluminium	0.276	(0.046)*	0.706	(0.038)*	0.39
Copper	0.241	(0.032)*	0.812	(0.019)*	8.74*
Zinc	0.210	(0.031)*	0.815	(0.020)*	2.03
Nickel	0.427	(0.049)*	0.700	(0.027)*	19.6*
Wheat	0.150	(0.022)*	0.865	(0.014)*	1.93
Corn	0.090	(0.013)*	0.901	(0.012)*	2.15
Soy	0.241	(0.030)*	0.718	(0.032)*	3.83*
Beef	0.315	(0.043)*	0.699	(0.031)*	0.82
Logarithm of price levels					
Oil	0.441	(0.050)*	0.617	(0.038)*	3.26
Coal	0.214	(0.039)*	0.755	(0.036)*	3.95*
Gas[d]	0.520	(0.063)*	0.491	(0.043)*	3.66
Aluminium	0.179	(0.041)*	0.748	(0.052)*	4.28*
Copper	0.065	(0.023)*	0.878	(0.035)*	10.51*
Zinc	0.064	(0.021)*	0.896	(0.028)*	6.35*
Nickel	0.196	(0.029)*	0.799	(0.031)*	0.76
Wheat	0.062	(0.015)*	0.933	(0.013)*	0.58
Corn	0.016	(0.010)	0.942	(0.039)*	1.75
Soy	0.113	(0.031)*	0.676	(0.086)*	9.35*
Beef	0.155	(0.049)*	0.613	(0.039)*	9.39*

*Statistically significant at 5% confidence level.
[a] Only estimates of parameters ρ and ω are reported. Other model parameter estimates are available on request.
[b] 1991M1-2021M12.
[c] 1992M1-2021M12.
[d] 1985M1-2021M12.

As expected, volatility clusters do not emerge for FoodInd, while a significant increase of volatility can be appreciated in the second part of the period of (starting around 2005) for both MetInd and EneInd. For these indexes, this volatility dynamics seems consistent with the increased price turbulence observed in the same period as shown in Figure A1. In the case of individu-

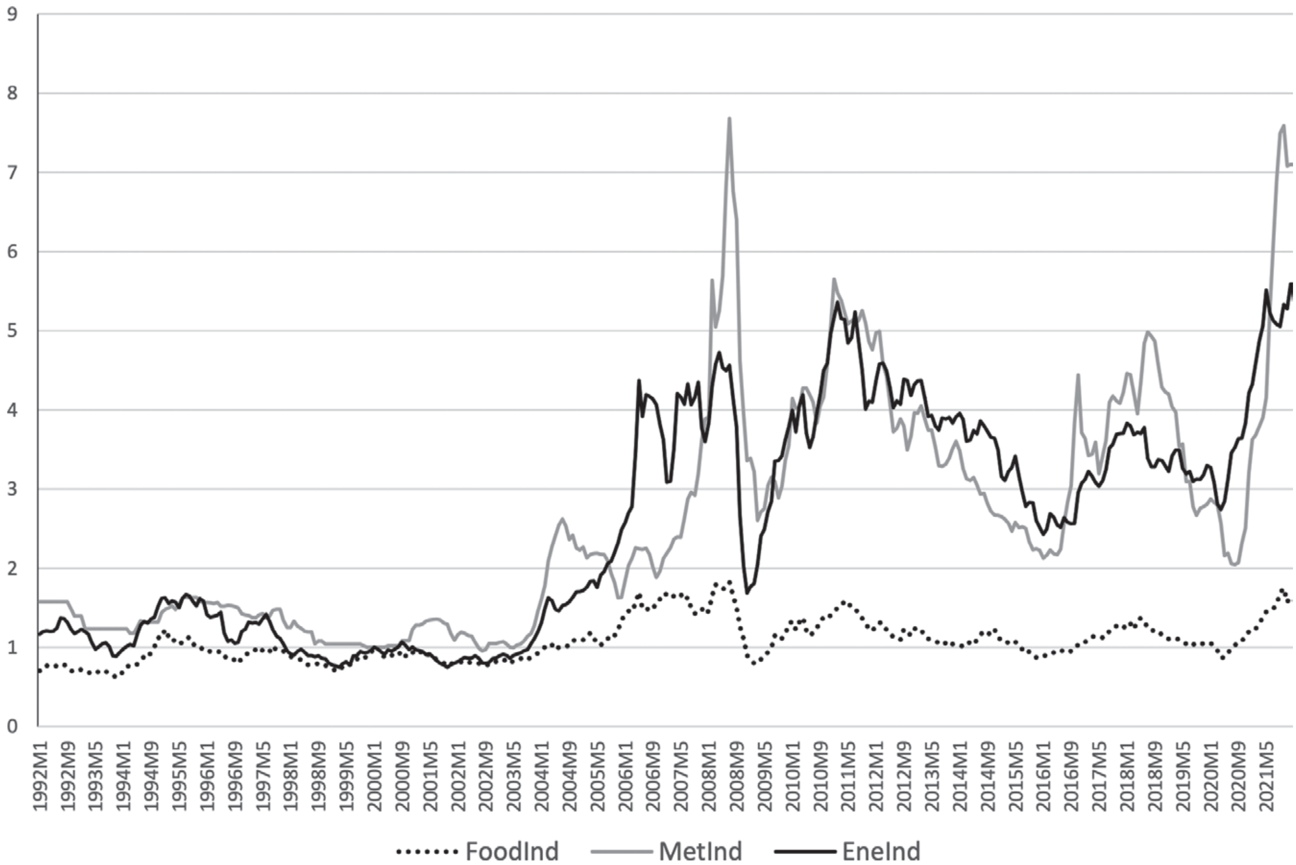


Figure 2. GARCH(1,1) model standard error in-sample prediction for commodity price indexes (2000M1=1) (1992M1-2021M12).

al series, predictions show huge volatility variations for oil and for all mineral and agricultural commodities. Clusters seem to be relatively rare and quite temporary in the first part of the period, while they become more frequent and longer, thus possibly permanent, from 2005 onwards. This seems even more true for CPI and therefore, but less intensively, for the inflation rate. CPI volatility sharply rises in 2005 and remains higher than in the previous period with only a drastic drop during years 2013-2014.

The question is whether the magnitude of this volatility clustering is consistent with the actual price turbulence or whether, in fact, we should look for alternative explanations.

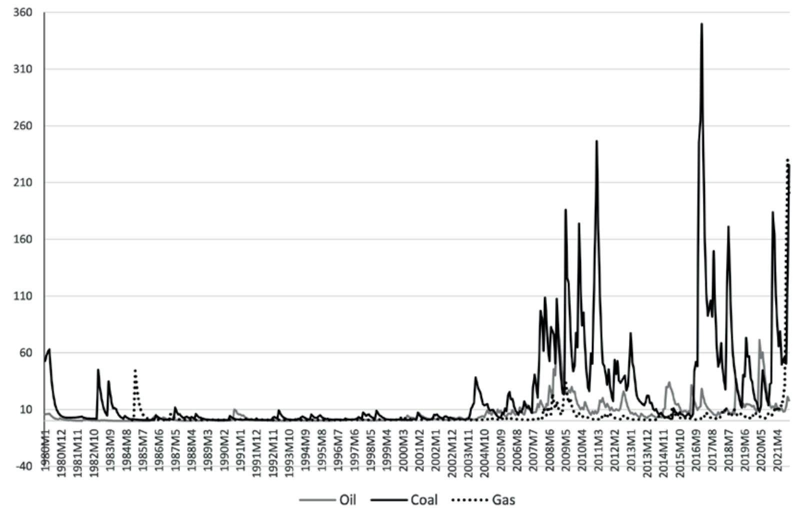
5.3. *Temporary bubbles*

Table 3 reports the sequence of tests for the presence of temporary bubbles as expressed by equations (5) and (6). As discussed, moving from ADF_0^1 to GSADF the tests improve in terms of recursiveness and flexibility, therefore in precision, in detecting the temporary explosive roots.[16] The presence of a temporary bubble is excluded in all cases (price indexes, individual price levels and logarithms of individual price levels) when the search of the bubble extends to the whole period (ADF_0^1). Something emerges with SADF with a temporary explosive root observed for MetInd and EneInd, and for the price level of all energy commodities, all minerals, and wheat. In the case of the logarithm of prices a bubble is detected only for oil. The generalised occurrence of temporary bubbles is eventually indicated by the GSADF test. With the only exclusion of beef (both the price level and its logarithm), at least one temporary explosive root is found in all the series.[17]

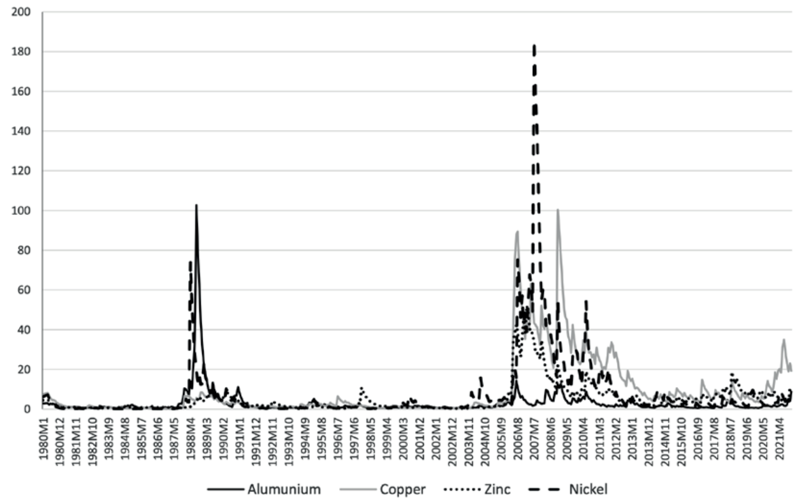
[16] It is worth noticing that the ADF_0^1 test in Table 3 (second column) corresponds to the ADF test with drift in Table 1 (third column) as the explosive bubble tests associated to equation (4) may include a drift but not a deterministic trend. However, strictu sensu, they are not the same test since the former is a right-tailed statistics so the critical values are different. The statistics itself slightly differs in some cases because the adopted specifications (i.e., lag structure) are not always the same.

[17] Notice that the difference between the SADF and GSADF tests are larger here than what was presented in previous studies (see Gharib et al., 2021, p. 5, in particular) arguably because, despite the number

a)



b)



c)

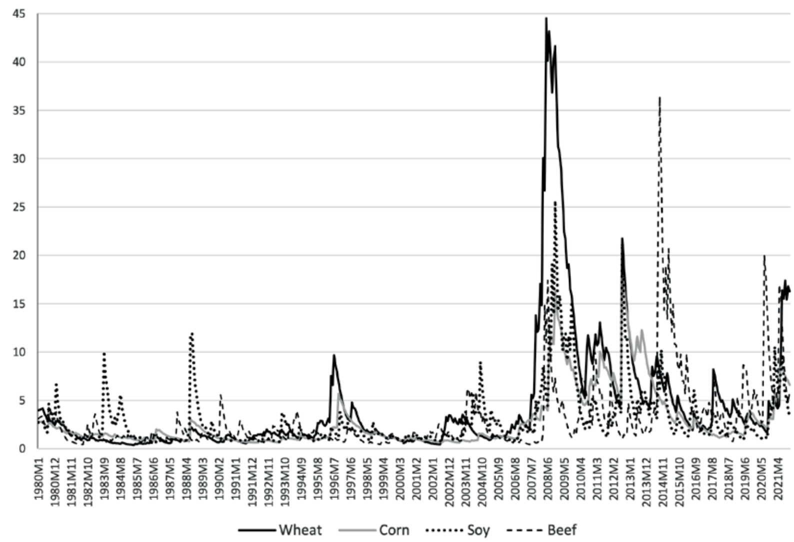


Figure 3a. GARCH(1,1) model standard error in-sample prediction for energy commodities (a), metals (b) and agricultural commodities (c) price levels (2000M1=1) (1980M1-2021M12).

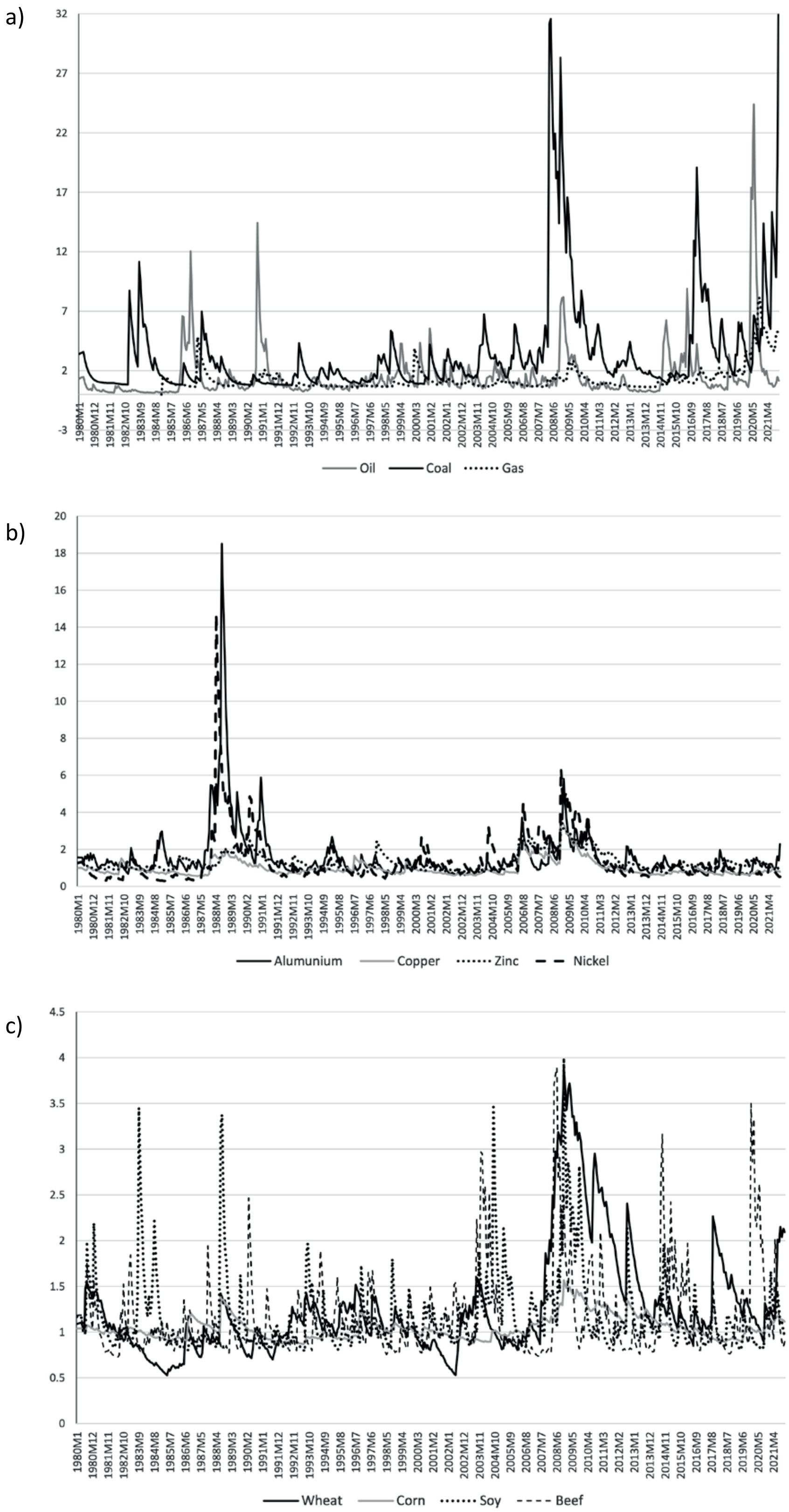


Figure 3b. GARCH(1,1) model standard error in-sample prediction for energy commodities (a), metals (b) and agricultural commodities (c) logarithm of prices (2000M1=1) (1980M1-2021M12).

Table 3. Temporary explosive root tests on commodity price indexes and commodity prices (1980M1-2021M12)[a].

Series	ADF_0^1	SADF	GSADF
Price indexes			
FoodInd[b]	-1.289	0.0487	3.644*
MetInd	-1.285	3.303*	7.170*
EneInd[c]	-1.167	4.907*	5.092*
CPI	0.288	0.854	3.189*
Price levels			
Oil	-2.352	3.843*	4.417*
Coal	-1.166	8.177*	8.762*
Gas[d]	-0.456	4.164*	6.619*
Aluminium	-2.524	2.405*	5.132*
Copper	-0.883	2.972*	4.750*
Zinc	-2.937	3.871*	5.908*
Nickel	-2.656	3.426*	5.491*
Wheat	-2.517	3.360*	3.795*
Corn	-2.151	0.357	3.462*
Soy	-2.478	-0.553	2.981*
Beef	-0.134	0.937	1.211
Logarithm of price levels			
Oil	-1.199	1.871*	2.275*
Coal	-1.500	0.414	2.511*
Gas[d]	-1.745	-0.135	2.891*
Aluminium	-3.168	-0.270	-2.816*
Copper	-0.858	-0.128	3.124*
Zinc	-1.827	0.057	3.583*
Nickel	-2.008	1.361	2.989*
Wheat	-2.410	1.120	3.098*
Corn	-1.756	0.513	2.306*
Soy	-2.032	-1.200	2.271*
Beef	-0.167	0.665	1.794

*Statistically significant at 5% confidence level with bootstrap critical values computed with 200 repetitions.
[a] All test specifications include 6 lags.
[b] 1991M1-2021M12.
[c] 1992M1-2021M12.
[d] 1985M1-2021M12.

In order to better appreciate how many bubbles occur and when, the BSADF tests (equation (7)) are computed. Results (with the critical values) are reported in Figure 4 for the three price indexes and in Figures 5a,b for the commodity price levels and logarithms, respectively. It appears that, for indexes, bubbles very sporadically emerge before and after the 2005-2008 period. On the contrary, over these four years the tests exceed the critical values several times for all the indexes. MetInd is the index for which this exceedance is more often observed.

In the case of individual price levels significant differences are found across the three groups. For energy prices, only in period 2005-2008 we observe one or more bubbles shared by the three prices. In the case of metals, beside that period, a common bubble is also observed in the mid-eighties. Agricultural commodities present a more composite situation: bubbles are more frequent and occur in the mid-eighties, mid-nineties, 2007-2008 and in the last decade. But they are often individual bubbles and, again, only in 2007-2008 we observe a bubble shared by most (except for beef) agricultural commodities. Qualitatively, results obtained with the price logarithms are similar even though, as could be expected, the bubbles are less frequent and, consequently, also the commonality of bubbles is more sporadic.

5.4. First movers and contagion

As discussed in previous sections, the focus of the present study is not on commodity price interdependence but on investigating the formation of temporary bubbles within individual price series in order to allow a real-time monitoring tool to inform on the formation of temporary bubbles, on the possible involvement of several commodities and on the first moving prices. The combination of the two alternative approaches here proposed allows to present their results in a form that permits an intuitive visualization of all this information about if and how co-exceedance is occurring.

Figures 6a,b aim to provide this easily interpretable visualization by displaying the periods of exceedance (volatility clusters or bubbles) for price levels and logarithms, respectively. Bubbles are dated on the basis of the BSADF tests. In the case of volatility, following Engle (1982, p 1003), exceedance is found any time the predicted volatility exceeds the double (in the case of price indexes) or the triple (in the case of individual commodity prices) of the average predicted volatility (i.e., standard error) over the two subperiods 1980M1-2000M12 and 2001M1-2021M12. Together with Table 4, these figures are also intended to provide an example of how the proposed approach can contribute to a real-time surveillance tool through an easily interpretable and periodically updatable dashboard visualization.

To summarize this evidence and better interpret it in terms of co-exceedance, Table 4 reports the beginning (the "exuberance date" to use the term of Gharib et al., 2021, p. 6) and the end (the "collapsing date") months of

of observations, the period covered here is quite long (more than 40 years).

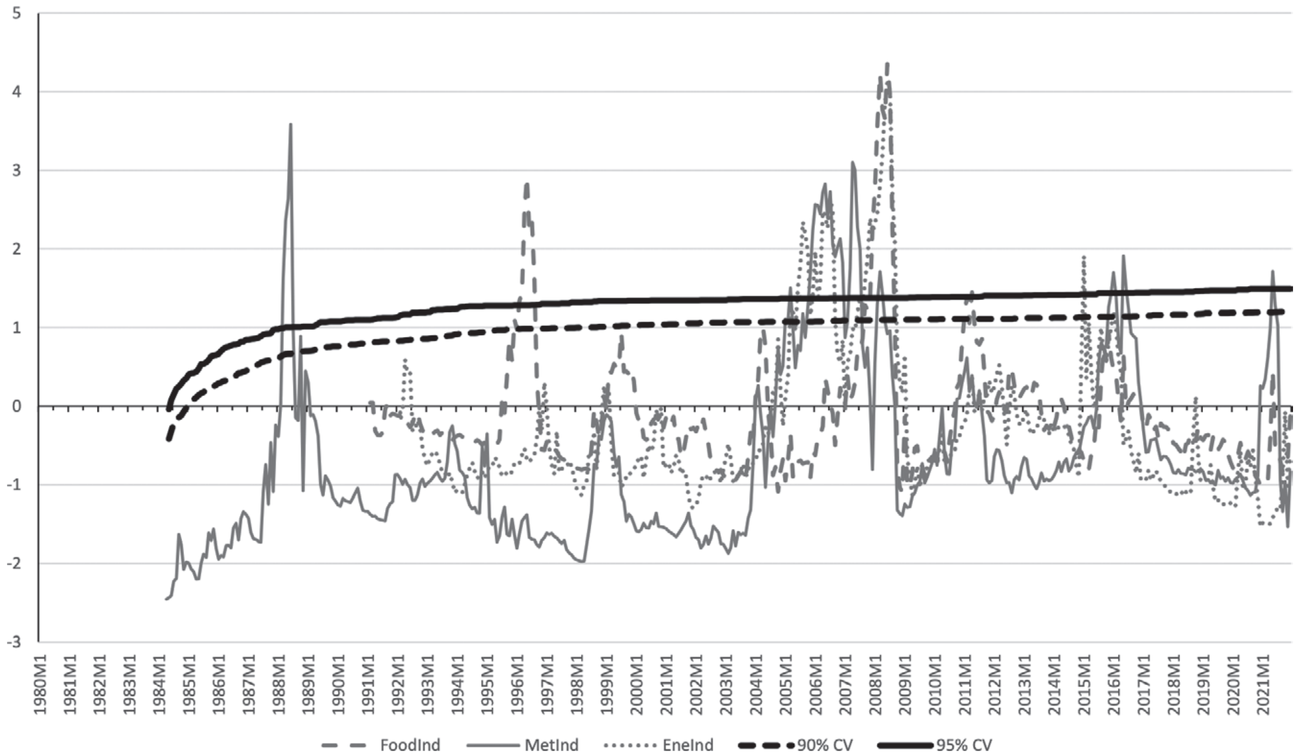


Figure 4. BSADF tests for indexes for commodity price indexes (1992M1-2021M12).

periods with at least three different commodities showing at least two consecutive months of exceedance, thus a co-exceedance in terms of volatility or common bubble for at least two consecutive months (Phillips et al., 2011). The table also reports: commodities showing this co-exceedance (second column); the commodity that can be identified as the first mover (third column), that is, the price whose exceedance started first before the period of co-exceedance; whether or not also CPI shows exceedance in the same period, and whether or not CPI can be considered the first mover (forth column).

In the case of price levels, it emerges that bubbles concentrate in the 2005-2008 period though in different moments involving different commodities. Basically, we can identify two main episodes. The first goes from 2005M8 to 2006M9. It only involves energy commodities and metals with oil and copper as first movers. CPI is itself involved in the bubble, as could be expected, but surprisingly it behaves as the first mover. The second episode is shorter and goes from 2008M2 to 2008M8. It involves all energy commodities wheat and corn but no minerals. Again, oil behaves as the first mover. This latter commodity actually seems to experience a single bubble from mid-2005 to the end of 2008. CPI is also involved but not as the first mover.

Volatility clusters emerging from the GARCH regressions show a significant difference compared to the bubbles. A first episode is found from mid-1988 to mid-1989, it concerns some minerals and agricultural commodities but no energy commodities. Wheat seems to be the first mover. Other four episodes, in fact behaving as a single one, can be detected from 2006M8 to 2009M8. In the first part of this period, the cluster exclusively involves metals and wheat. Then, other prices enter the group included energy commodities and, finally, also oil. In the very last part of this episode, the volatility clusters involve most (9 out of 11) commodities. If we consider this whole period as a single episode, the first mover seems to be nickel which sounds a little surprising. In the second part of the period, wheat and natural gas emerge as other possible candidates.

Two other volatility clusters can be found in the last decade of the period under investigation. One concerns a very short period (two months in mid-2012) and only involves agricultural commodities. The other concerns the very last months of the period of observation (2021M9-2021M12); it is short simply because it continues beyond the period of observation. This period of exceedance is not identified with the bubble testing arguably because the bubble has still to collapse. Future

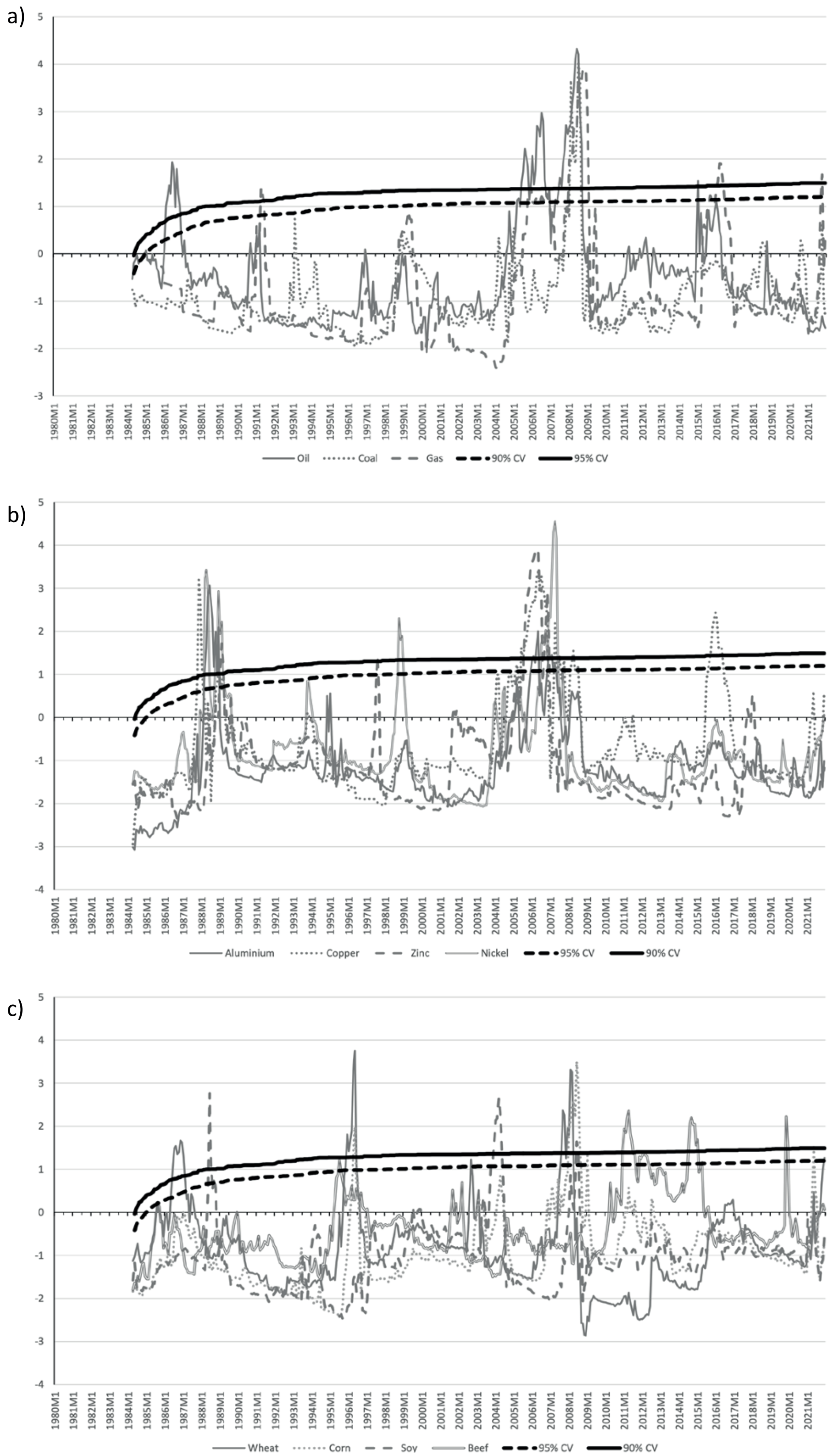


Figure 5a – BSADF tests for indexes for energy commodities (a), metals (b), agricultural commodities (c) price levels (1980M1-2021M12).

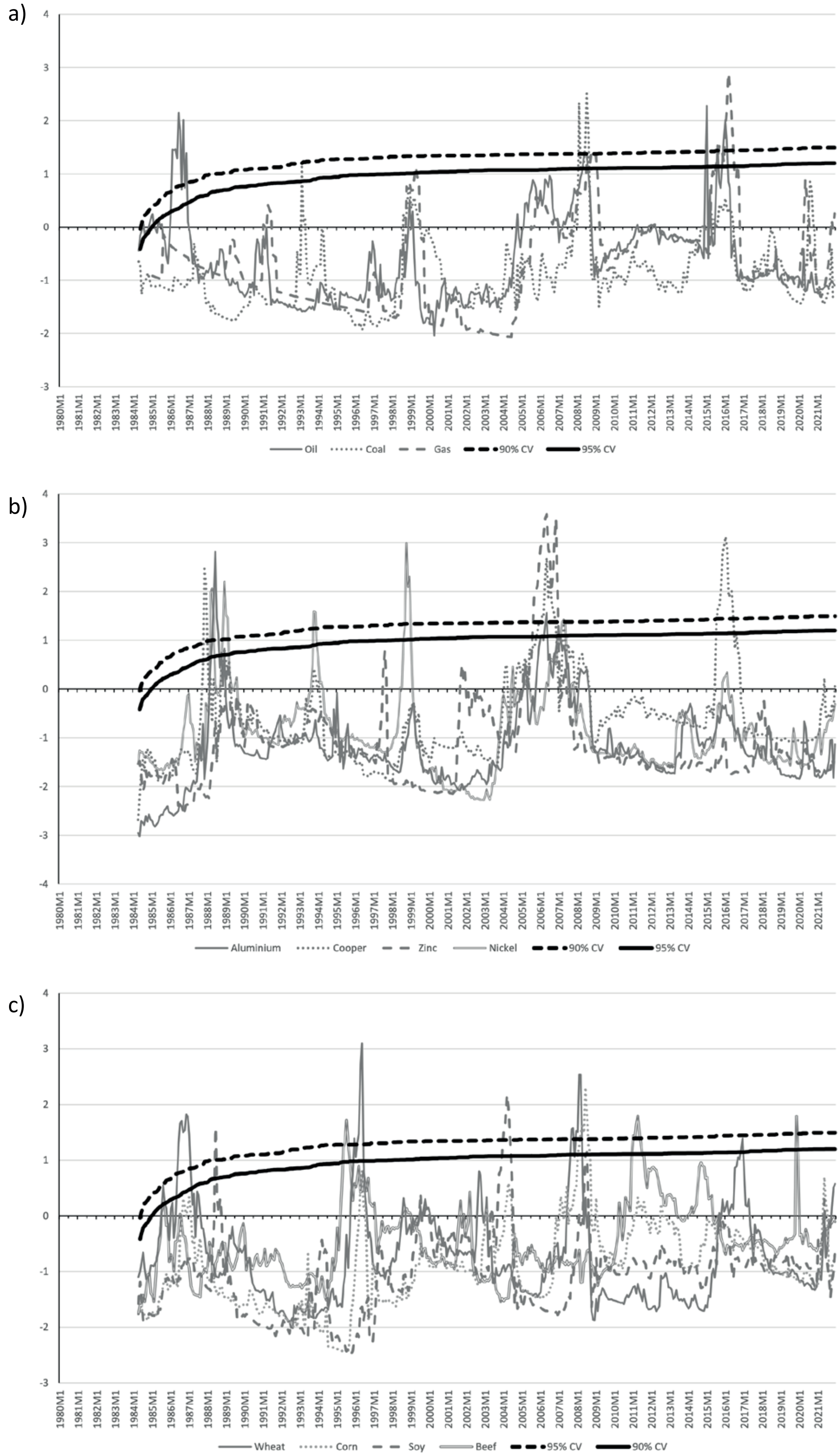


Figure 5b. BSADF tests for indexes for energy commodities (a), metals (b), agricultural commodities (c) logarithm of price levels (1980M1-2021M12).

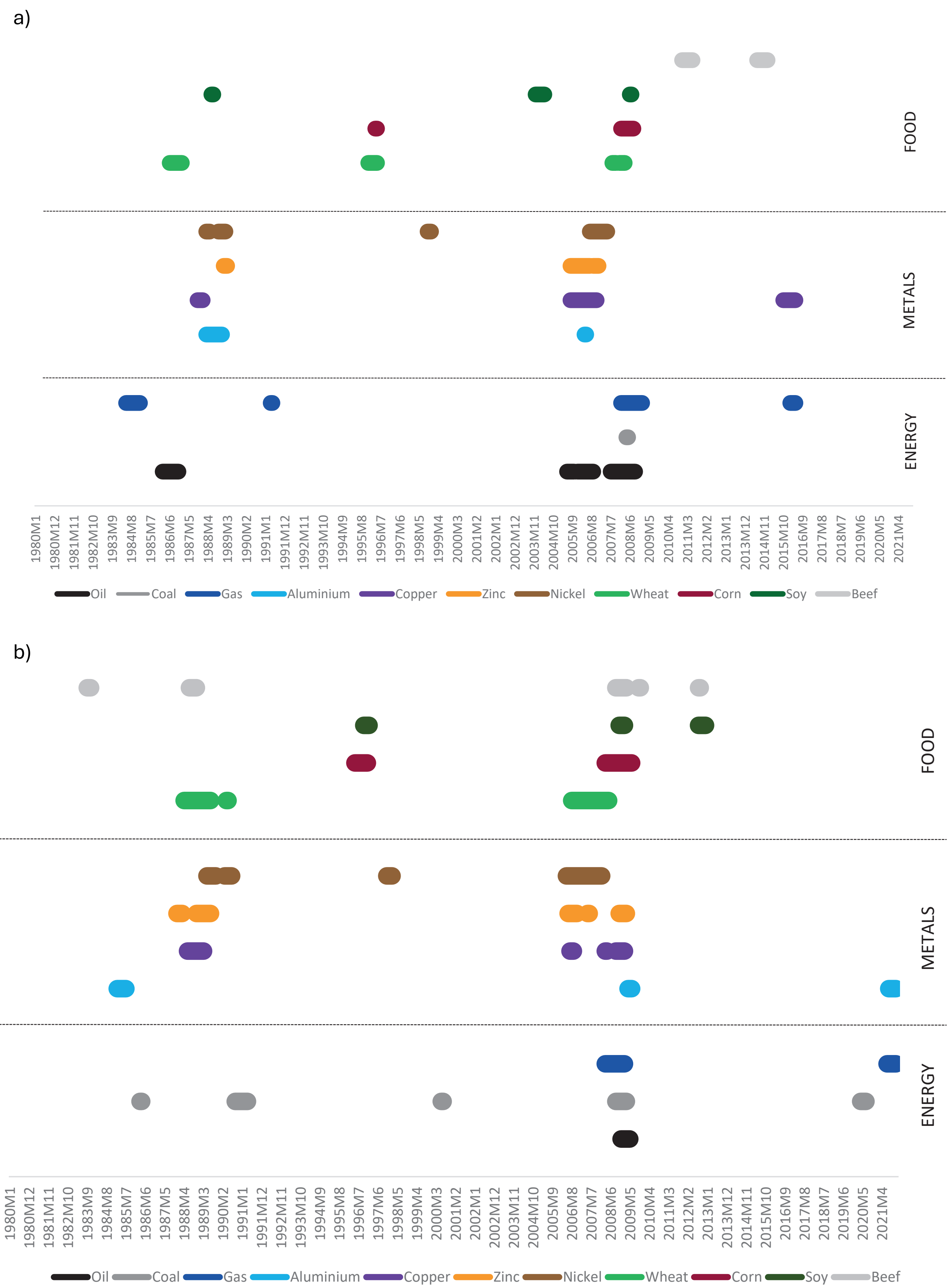


Figure 6a. Dating of explosive roots (a) and volatility clusters (b) for all commodity price levels (1980M1-2021M12) (see Table 4 for details).

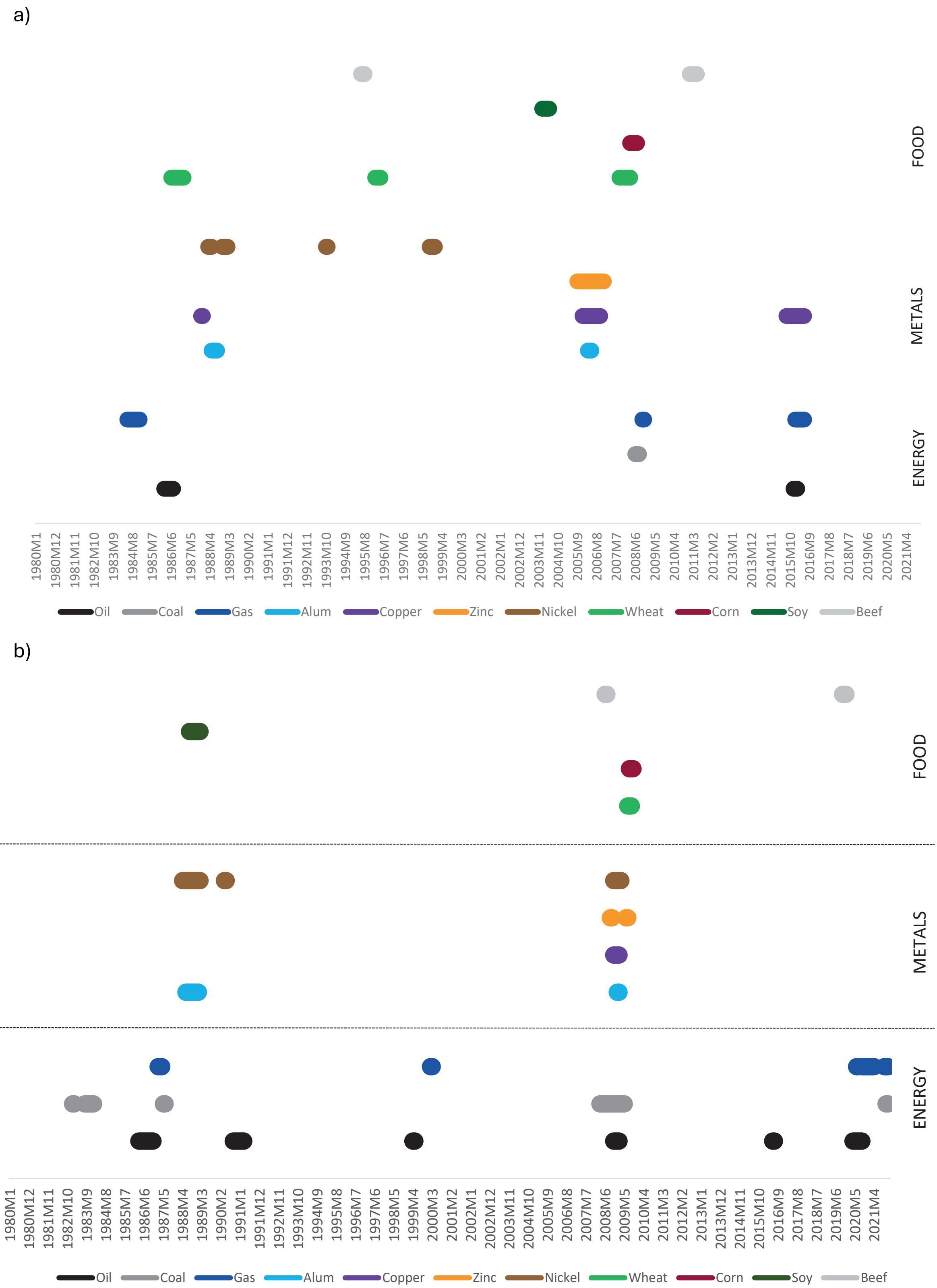


Figure 6b. Dating of explosive roots (a) and volatility clusters (b) for all commodity logarithms of price levels (1980M1-2021M12) (see Table 4 for details).

Table 4. Dating of temporary explosive roots and volatility clusters for commodity price levels and logarithm of levels (1980M1-2021M12).

Period	Commodities	First mover[c] (date)	CPI: Y/N; first mover (Y/N & date)[d]
	Price levels		
Bubbles[a]			
2005M8-2005M10, 2006M1, 2006M3, 2006M6	Oil, Copper, Zinc	Oil, Copper (2005M6)	Y; Y (2005M3)
2006M2, 2006M4-2006M5	Oil, Aluminium, Copper, Zinc		
2006M7, 2006M9	Oil, Copper, Zinc Nickel		
2006M10-2006M12	Oil, Copper, Zinc		
2008M2-2008M7	Oil, Coal, Gas, Wheat, Corn	Oil (2007M3)	Y; N
2008M5, 2008M8	Oil, Coal, Gas, Corn		
Volatility Clusters[b]			
1988M7-1988M10	Copper, Wheat, Beef	Wheat (1988M4)	N
1988M11-1989M7	Copper, Zinc, Nickel, Wheat		
2006M8-2006M11	Copper, Zinc, Nickel, Wheat	Nickel (2006M5)	N
2007M4-2007M12	Copper, Zinc, Nickel, Wheat		
2008M3-2008M8	Gas, Copper, Wheat, Corn	Wheat (2006M8)	N
2008M9-2009M8	Oil, Gas, Coal, Aluminium, Copper, Zinc, Corn, Soy, Beef	Gas (2008M3)	Y; N
2012M7-2012M8	Corn, Soy, Beef	Soy (2012M8)	N
2021M9-2021M12	Gas, Aluminium, Copper	Gas (2021M7)	Y; N/Y(2021M7)
	Logarithm of price levels		
Bubbles[a]			
Period	Commodities	First mover (date)	CPI: Y/N; first mover (Y/N & date)
2005M12-2006M10	Aluminium, Copper, Zinc	Zinc (2005M9)	Y; Y (2005M3)
2008M6-2008M7	Oil, Coal, Wheat, Corn	Wheat (2008M2)	Y; N
2015M12-2016M6	Oil, Gas, Copper	Copper (2015M8)	N
Volatility Clusters[b]			
Period	Commodities	First mover (date)	CPI: Y/N; first mover (Y/N & date)
1988M4-1989M1	Aluminium, Nickel, Soy	Aluminium (1987M12)	Y; N
2008M11-2009M3	Oil, Coal, Aluminium, Copper, Nickel	Coal (2008M3)	Y; N

[a] The dating of the bubble corresponds to periods when at least 3 commodities show explosive roots, that is BSADF test significant at 5% confidence level with bootstrap critical values computed with 200 repetitions. Only periods with at least two consecutive months of exceedance are reported.
[b] The dating of the volatility clusters corresponds to periods when predicted volatility (i.e., standard error) is larger than three times the subperiod (1980M1-2000M12; 2001M1-2021M12) average volatility. Only periods with at least two consecutive months of exceedance are reported.
[c] The first mover is the price of the group whose exceedance started first before the period of co-exceedance.
[d] The first Y/N indicates whether or not also CPI shows exceedance in the same period; the second Y/N indicates whether or not CPI can be considered the forst mover (in parenthesis the date).

investigations will confirm the nature and scope of the current period of exuberance. The cluster identified here suggests that it concerns both energy prices and metals but it is likely driven by the former and, in particular, by natural gas.

Two major facts seem to emerge from this analysis of co-exceedance. First of all, the correspondence between bubbles and volatility cluster detection is limited. Periods correspond in the case of the major episode that occurred between 2005 and 2008. But for the rest of the sample, the detection of the episodes of co-exceedance does not correspond. Also the involved commodities significantly differ and, consequently, the first movers. Bubble detection seems to stress more the dynamics of energy commodities, and oil in particular, while volatility clusters point more to metals and agricultural commodities. A final difference concerns the involvement of CPI that seems very limited in the case of clusters while it is more relevant for bubbles.

The second notable fact is the difference between price levels and price logarithms. As the logarithmic transformation re-scales the data and, therefore, scales down their variability, respective results are expected to make the more robust evidence emerge: the number of individual episodes may slightly decline and the number of common episodes is expected to substantially reduce. It turns out that the number of episodes of co-exceedance detected on price logarithms is lower, as expected, for both bubbles and volatility clusters. But the nature of these episodes does not necessarily correspond with what is observed on price levels and this lack of robustness passing from levels to logarithms seems more evident for bubbles than for volatility clusters. The involved commodities are not necessarily the same, as well as the first movers, and also the involvement of the CPI shows some difference. In general terms, when the logarithms are considered, it seems more difficult to find some general pattern in the results, especially in terms of a key role of some commodities like the energy ones.

Looking for regularities, two special cases are worth noticing here. The first concerns the oil price. Properties and behaviour of this commodity price emerging in the present work confirm the bubble detection and dating reported in previous studies, particularly in Su et al. (2017) and Zhao et al. (2021).[18] It could also be argued that oil price has to behave as a sort of upstream price since it enters as a production cost in most downstream production processes, included farming and mining activities. But this role of oil as first mover is not generally observed and seems to emerge only in bubble testing with price levels.

The second interesting role is that played by agricultural commodities. On the one hand, they can be considered as downstream prices compared to energy commodities and metals. But, for this reason, they can severely impact on CPI dynamics. From our results, it emerges that agricultural commodity prices seem to be a little more "stable" in the sense that episodes of exuberance (bubbles or volatility clusters) are less frequent and shorter. At the same time, while energy commodities and metals are apparently more interdependent, agricultural prices seem to follow more autonomous patterns and are less likely to act as first movers and, thus, to be suitable candidates to drive the other commodity prices and of the CPI.

What can we finally conclude about the evidence on the linkage between commodity prices and CPI? While results tend to confirm some stochastic properties of the CPI that may explain periods of exuberance, the evidence that these periods are the consequence of analogous episodes in commodity prices is poor. The major episode of price exuberance between 2005-2008 confirms, as could seem obvious, a connection between commodity prices and CPI, maybe because this episode involves a large number of commodities, though in different times. In fact, this connection seems quite weak beyond this period. And also within this 2005-2008 period it is not clear whether commodity price exuberance induced a CPI response or if it is actually the other way round. This lack of evidence should not be surprising and evidently asks for further investigation. Other very recent empirical investigations (Lian and Freitag, 2022), for instance, suggest that oil price shocks do not always imply a shock on CPI and sometime this latter may move independently and also precede the former.

6. COMPARISON WITH OTHER STOCHASTIC PROCESSES AND APPROACHES

For the sake of comparison and in order to validate the results here obtained, it is worth investigating the commonality of the commodity price dynamics also with more conventional approaches. Rather than focusing on co-exceedance, as in the present study, these approaches look for the commonality of the stochastic generation processes (i.e., co-movement and the consequent price interdependence) under the typical hypothesis of either stationary or non-stationary linear DGP, possibly with a drift and/or a trend (Esposti, 2021). As already discussed in Section 2, in order to capture the complexity and non-linearity of these series a further occurrence that can be considered consists in admitting that series undergo, in one or more points in time, a structural break in either the drift or the trend (or in both) (Baum, 2005). In principle, under multiple breaks, these stochastic processes could explain the presence of periods of extremely high (or low) prices (the "bubbles") as a sequence of two structural breaks with the latter eventually compensating the former and thus making its effect only temporary.

Table A2 (Annex 3) reports a battery of tests specifically designed to assess whether these more conventional stochastic processes represent suitable alternatives to the two co-exceedance processes here considered. Four tests are reported. They all confront a unit-root process (the null hypotheses of the tests) with a stationary process

[18] Su et al. (2017, p. 6) conclude that "there are explosive multiple bubbles in the WTI oil market in 1990, 2005, 2006, 2008 and 2015. Generally, oil bubbles mostly occur during the period of price volatility".

presenting one or two structural breaks in some terms of the process itself.[19] All tests admit endogenous breaks, thus not only do they test their presence but they are also able to date these breaks.

The first two tests consist in two specifications of the Zivot-Andrews (ZA) unit root test (Zivot and Andrews, 2002) admitting only one structural break in either the intercept or both intercept and trend. Test results largely accept unit-root processes without a break against the presence of a structural break within stationary series. The only exceptions are coal and soy in the price levels and only soy in the logarithms of prices. The break date is similar, late 2006-early 2007, and corresponds to one of the major periods of co-exceedance identified in previous sections. Not only is the break accepted for only two commodities but, more importantly, it can not explain why and how, once started, the period of turbulence then comes to an end since the structural break introduces a permanent change in the process.

The other two tests, consisting in two variants of the Clemente-Montañés-Reyes unit root test (CMR) (Clemente et al., 1998), can be helpful in this respect. In this case, the statistical significance of the breaks themselves can be assessed as they enter in the test specification as time dummies with the respective coefficients. More importantly, this test admits two structural breaks within the stationary process thus allowing the combination of the two breaks to capture a temporary change in the process, like in the case of periods of price surge. The test can be performed under two different natures of the breaks: a sudden change in the series (the additive outliers, or AO, model) or a gradual shift in the mean of the series (the innovational outliers, or IO, model). Evidently, the former, much more than the latter, is expected to capture the short periods of price turbulence.

Although CMR tests confirm how difficult it can be, over such a long period of time, to univocally identify clear stable stochastic processes for any given commodity and, even more, commonality across commodities in this respect, they still provide some interesting indications. One the one hand, the CMR test under the AO model seems to confirm the main evidence emerging from the ZA test results without any relevant difference between price levels and logarithms: for most commodity prices (oil being the only exception) a non-stationary process is accepted against a stationary process with structural breaks. When the IO model is considered, however, the CMR test indicates that for many commodities (all energy prices, aluminium, zinc, corn and FoodInd itself) a mean-reverting process under two structural breaks is accepted. Even more interestingly, this test indicates that, for both AO and IO cases, the structural breaks are always statistical significant (with only one exception). In some cases, the interval between the two breaks is too wide (more than three years) to really capture a period of price exuberance (see the CPI case, for instance). In other cases, however, the time window between the two breaks seems quite consistent with the periods of exceedance here identified, as shown in Figures 6a,b. This is the case, in particular, of coal and all metals.

As already discussed, with respect to the purpose of the present study, the introduction of structural breaks may seem an unnatural way to capture co-exceedance: it still maintains the linear specification of the DGP possibly with a permanent change while here the intention is to identify a DGP with temporary non-linearities. It follows that admitting structural breaks within the stochastic process representation may still confound short-term and long-term dynamics within the price series. Nonetheless, present results suggest that multiple breaks within an appropriate specification eventually constitute a sort of spline process capable to proxy temporary non-linearities. Even though not considered further here, this kind of approach, together with the introduction of multiple structural breaks within non-linear processes (Bai and Perron, 2003; Caporale et al., 2020), can represent a promising alternative empirical strategy in future research in the field.[20]

There is a final aspect to be considered about the introduction of structural breaks as a valid alternative to capture co-exceedance. It concerns the identification of the first-moving commodities and the possible consequent contagion process. As shown, within the proposed approach, this identification is made only qualitatively by identifying and then visualizing when, commodity by commodity, the periods of exuberance start and end (see Figures 6a,b). Very often, however, within the empirical literature this identification is formally pursued using Granger causality testing (Esposti and Listorti, 2013). This approach must satisfy the prerequisite that series under investigation show the same stochastic properties (they are all either I(0) and I(1)), and then it requires the estimation of multiple-equation linear models (in the form of VAR or VEC models, respectively) representing the common movement from which direction and nature of price interdependence (or transmission) can be assessed. Within this representation one or more struc-

[19] For more details on the ZA and CMR tests, also see Baum (2005).

[20] The use of international or global commodity prices, as well as the widely heterogenous dating of these structural breaks across commodities, makes it hard to speculate on the possible linkage between them and external shocks like, for example, policy regime changes. However, this investigation may represent a further direction of research for the future.

tural breaks can be included (as time dummies) to possibly capture some changes in the linear relationships, thus admitting temporary non-linearities.

Results here presented demonstrate how the prerequisite of this empirical strategy to detect first movers and contagion can be challenging. A common DGP is impossible to find when all price series are considered. But even concentrating on individual commodity groups, Tables 1 and 5(??) suggest there is always at least one commodity showing a different underlying stochastic process compared to the others. Apparently, an interesting case is that of energy commodities under the IO specification of the CMR test: when two structural breaks are admitted they all behave as stationary processes with a drift and a deterministic trend. Therefore, an attempt to perform Ganger causality testing can be made here by estimating a VAR model with four endogenous variables: the three energy prices (oil, coal and gas prices) and the CPI, since it quite robustly emerges as a I(0) process. The VAR specification also includes a drift, a deterministic trend and two time dummies representing the two breaks at 2003M11 and 2013M5. Table A3 (Annex 3) reports the results of the respective Granger causality tests and the estimated coefficients of the two structural breaks.[21]

As often occurs with Granger causality testing, results are not easily interpretable. However, they confirm some of the evidence obtained with our proposed approach. It seems hard to identify an indisputable driving price and, in particular, this does not seem the case of the oil price. When price levels are considered, oil and coal show a reciprocal Granger causation, while natural gas is only Granger caused by the coal price. Oil and coal price both Granger-cause the CPI response, while CPI itself does not Granger-cause any of the energy prices as could be expected. Coal rather than oil seems to be the driving price, if any, and this seems to be reinforced when the logarithm of prices are considered instead of the levels. The presence of structural breaks, though suggested by tests reported in Table A2, is not confirmed by VAR estimation coefficients associated to respective time dummies are mostly not statistically different from zero.

Compared to the approach here proposed, which is based on the search of co-exceedance periods (thus admitting non-linearities in the DGP) rather than on linear price interdependence, these more conventional stochastic processes do not seems to provide any helpful additional information. On the contrary, they seem to fail in the search of common periods of exuberance over a large group of commodities, thus they do not seem appropriate for designing a real-time surveillance dashboard informing a prompt policy response. Nonetheless, even in these approaches recent contributions have opened new interesting perspectives that may deserve careful consideration in future research. For instance, the implementation of non-linear Granger causality testing seems particularly promising (Shahzad et al., 2021).

7. CONCLUSIVE REMARKS

Periods of commodity price exuberance raise political concerns particularly for their possible impact on the inflation rate. Timely interventions by the appointed institutions are often invoked but do not necessarily prove to be effective in preventing or neutralizing these episodes. After all, common price spikes (thus, co-exceedance) might not imply a common policy response since for some commodities exuberance tends to be motivated by real drivers while in other cases financial phenomena are prevalent. Understanding the mechanisms underlying generation, transmission and, then, collapse of co-exceedance remains relevant to design the proper, possibly differentiated, policy response. But in the shorter term an appropriate policy response may just need a timely detection of the price surge and of the degree of diffusion across commodities.

The present paper aims to develop a single methodological approach, albeit based on alternative stochastic processes, that does not assume common movement and price interdependence but only co-exceedance, thus commonality occurring only within the periods of exuberance. This approach is able to detect whether such a period occurs, when it starts and when it ends, the degree of diffusion across commodities, the possible presence of driving prices and, eventually, the transfer to the inflation rate. On this basis, the proposed methodology is intended to offer an easily interpretable visualization of the critical information it generates.

Results presented indicate that the different approaches considered (bubbles and volatility cluster detection in both price levels and logarithms) are able to provide clear indications on when the exceedance occurs, on its overlapping across commodities and on possible first movers. However, this evidence is not concordant or, at least, robust across the different approaches making the final outcome of the analysis, and the policy implication itself, severely dependant on the analyst's choices in this respect. Results do not even agree on the involvement of the CPI in these episodes of exuberance, therefore on the transmission of commodity price spike to inflation rate.

[21] For the sake of space limitation, the VAR model estimates are not reported here but are available upon request.

On the basis of this discrepancy, it seems wise to develop the abovementioned policy tool in a way that prudently admits both processes and elaborates information from a combination of them. At the same time, this discrepancy points to room for further methodological improvements. After all, both competing representations of the origin of exceedance, volatility clusters and temporary bubbles, show pros and cons and this makes it difficult to draw a general preference for one or the other. GARCH modelling seems to represent more permanent changes in volatility rather than short periods of exuberance. Furthermore, it hardly combines volatility clusters with a non-stationary process in the price levels. At the same time, bubble detection applies well to positive bubbles, therefore periods of exuberance then followed by a collapse, but it does not necessarily succeed in case of negative bubbles, that is episodes that start with a price crash (Gharib et al., 2021, pp. 3-4).[22] In fact, bubble detection can only by applied *ex post*, therefore when the bubbles have already collapsed. This substantially limits the actual applicability of the approach by analysts and policy makers. Moreover, currently available tests only apply to univariate bubble detection. Multivariate bubble testing has not yet been proposed and this prevents a direct investigation of contagion across commodities.

Regarding all these aspects, results obtained in the present study also suggest the extension of the adopted tool to other stochastic processes, particularly those expressing non-linear dynamics of commodity prices in both level and variance. Multiple breaks, fractional integration, fractal and wavelet analysis are some examples in this direction. Finally, it would be particularly helpful to replicate these results on higher frequency price data. Weekly or daily prices, if available, might definitely be useful to better refine this real-time surveillance policy tool making it more timely and accurate. However, these data might also bring about more statistical noise, thus making the identification of co-exceedance more difficult and uncertain, and increasing the risk of false alarms. Therefore, replication of the present analysis on these data could allow to assess the advantages and disadvantages in the use of higher frequencies.

REFERENCES

Agustini, F.W., Affianti, I.R., Putri, E.R.M. (2018). Stock price prediction using geometric Brownian motion. *Journal of Physics: Conference Series* 974, 012047.

Bai, J., Perron, P. (2003). Computation and analysis of multiple structural change models. *Journal of Applied Econometrics* 18, 1–22 (2003).

Baum, C.F. (2005). Stata: The language of choice for time-series analysis? *The Stata Journal* 5(1), 46–63.

Baur, D.G., Dimpfl, T. (2018). The asymmetric return – Volatility relationship of commodity prices. *Energy Economics* 76: 378-387.

Byrne, J.P., Sakemoto, R., Xu, B. (2020). Commodity price co-movement: heterogeneity and the time-varying impact of fundamentals. *European Review of Agricultural Economics* 47(2), 499–528.

Campbell, J.Y., Lo A.W., MacKinlay, A.C. (1996). *The Econometrics of Financial Markets (2nd Edition)*. Princeton University Press, Princeton.

Caporale, G.M., Gil-Alana, L.A., Poza, C. (2020). Persistence, non-linearities and structural breaks in European stock market indices. *The Quarterly Review of Economics and Finance* 77, 50–61.

Chan, W.H., Maheu, J.M. (2002). Conditional Jump Dynamics in Stock Market Returns. *Journal of Business & Economic Statistics* 20(3), 377-389.

Chan, N.H. (2010). *Time Series: Applications to Finance with R and S-Plus (2nd Edition)*. Wiley, Hoboken.

Chang, K.L. (2012). The time-varying and asymmetric dependence between crude oil spot and futures markets: Evidence from the Mixed copula-based ARJI-GARCH model. *Economic Modelling* 29, 2298-2309.

Clemente, J., Montañés, A., Reyes, M. (1998). Testing for a unit root in variables with a double change in the mean. *Economics Lettters*. 59(2), 175–182.

Corradi, V., Swanson, N.R. (2006). The effect of data transformation on common cycle, cointegration, and unit root tests: Monte Carlo results and a simple test. *Journal of Econometrics* 132, 195–229.

Cromwell, J.B., Labys, W.C., Kouassi, E. (2000). What color are commodity prices? A fractal analysis. *Empirical Economics* 25(4), 563-580

Cuestas, J.C., Gil-Alana, L.A. (2016). A non-linear approach with long range dependence based on Chebyshev polynomials. *Studies in Nonlinear Dynamics and Econometrics* 23, 445–468.

Dawson, P.J., Sanjuan, A.I., White, B. (2006). Structural breaks and the relationship between barley and wheat future prices on the London international financial futures exchange. *Review of Agricultural Economics* 28(4), 585–594.

Diba, B.T., Grossman, H.I., 1988. Explosive rational bubbles in stock prices? *American Economic Review* 78, 520–530.

Enders, W. (1995). *Applied Econometric Time Series*. New York: John Wiley & Sons.

[22] As an example of a negative bubble in the oil price, Gharib et al. (2021, p.1) presents the case of the negative daily price of Brent observed on 21 April 2020.

Engle, R.F. (1982). Autoregressive Conditional Heteroscedasticity with Estimates of the Variance of United Kingdom Inflation. *Econometrica* 50(4), 987-1007.

Esposti, R. (2021). On the long-term common movement of resource and commodity prices. A methodological proposal. *Resources Policy* 72, 102010.

Esposti, R. (2022). Who moves first? Commodity price interdependence through time-varying Granger causality. Quaderno di Ricerca n. 471, Dipartimento di Scienze Economiche e Sociali, Università Politecnica delle Marche.

Esposti, R., Listorti, G. (2013). Agricultural Price Transmission across Space and Commodities during Price Bubbles. *Agricultural Economics* 44 (1), 125-139.

Esposti, R., Listorti, G. (2018). Price transmission in the Swiss wheat market: does sophisticated border protection make the difference? *International Trade Journal* 32(2), 209-238.

Fackler, P.L., Goodwin, B.K. (2001). Spatial price analysis. In: Gardner, B.L., Rausser, G.C. (eds.), *Handbook of Agricultural Economics. Volume 1B*. Chapter 17. Elsevier Science, Amsterdam, pp. 972–1025.

FAO, IFAD, IMF, OECD, UNCTAD, WFP, World Bank, WTO, IFPRI, UN-HLTF on Global Food and Nutrition (2011). Price Volatility in Food and Agricultural Markets: Policy Responses. World Bank, Washington, DC.

Garzón, A.J., Hierro, L.A. (2022). Inflation, oil prices and exchange rates. The Euro's dampening effect. *Journal of Policy Modeling* 44 (1), 130-146.

Gharib, C., Mefteh-Wali, S., Serret, V., Ben Jabeur, S. (2021). Impact of COVID-19 pandemic on crude oil prices: Evidence from Econophysics approach. *Resources Policy* 72, 102392.

Glynn, J., Perera, N., Verma, R. (2007). Unit-root tests and structural breaks: a survey with applications. *Journal of Quantitative Methods for Economics and Business Administration* 3 (1), 63–79.

Gürkaynak, R.S., 2008. Econometric tests of asset price bubbles: taking stock. *Journal of Economic Surveys* 22, 166–186.

Ibrahim, S.N.I., Misiran, M., Laham, M.F. (2021). Geometric fractional Brownian motion model for commodity market simulation. *Alexandria Engineering Journal* 60, 955–962.

Ider, G., Kriwoluzky, A., Kurcz, F., Schumann, B. (2023). Addressing inflationary risks in the face of high energy prices: what can the ECB do? Economic Governance and EMU Scrutiny Unit (EGOV), Directorate-General for Internal Policies, European Parliament, Brussels.

Li, N., Ker, A., Sam, A.G., Aradhyula, S. (2017). Modeling regime-dependent agricultural commodity price volatilities. *Agricultural Economics* 48, 683–691.

Lian, W., Freitag, A. (2022). Inflation Dynamics in Advanced Economies: a Decomposition into Cyclical and Non-Cyclical Factors. IMF Working Papers, WP/22/91, International Monetary Fund, Washington.

Listorti, G., Esposti, R. (2012). Horizontal price transmission in agricultural markets: fundamental concepts and open empirical issues. *Bio-based and Applied Economics*, 1(1), 81-108.

Mutascu, M.I., Albulescu, C.T., Apergis, N., Magazzino, C. (2022), Do gasoline and diesel prices co-move? Evidence from the time-frequency domain. *Environmental Science and Pollution Research*, 29, 68776-68795.

Otero, J., Baum, C. (2021). Unit-root tests for explosive behavior. *The Stata Journal* 21(4): 999–1020.

Phillips, P.C.B., Shi, S. (2020). Real time monitoring of asset markets: bubbles and crises. In H. D. Vinod and C. R. Rao (Eds.), *Handbook of Statistics: Financial, Macro and Micro Econometrics Using R*. Volume 42, pp. 61{80. Amsterdam: Elsevier.

Phillips, P.C.B., Shi, S., Yu, J. (2015). Testing for multiple bubbles: Historical episodes of exuberance and collapse in the S&P 500. *International Economic Review* 56(4), 1043-1077.

Phillips, P.C.B., Wu, Y., Yu, J. (2011). Explosive behavior in the 1990s NASDAQ: When did exuberance escalate asset values? *International Economic Review* 52(1), 201-226.

Shahzad, F., Bouri, E., Mokni, K., Ajmi, A.N. (2021). Energy, agriculture, and precious metals: Evidence from time-varying Granger causal relationships for both return and volatility. *Resources Policy* 74, 102298.

Stigler, M. (2011). Commodity prices: Theoretical and empirical properties. In: Prakash, A. (ed.), *Safeguarding Food Security in Volatile Global Markets*. FAO, Rome, pp. 25–41.

Su, C.-W., Li, Z.-Z., Chang, H.-L., Lobonţ, O.-R. (2017). When Will Occur the Crude Oil Bubbles? *Energy Policy* 102, 1–6.

Taleb, N.N. (2009). Errors, robustness, and the fourth quadrant. *International Journal of Forecasting* 25, 744–759.

Wang, D., Tomek, W.G. (2007). Commodity Prices and Unit Root Tests. *American Journal of Agricultural Economics* 89(4), 873-889.

Zhao, Z., Wen, H., Li, K. (2021). Identifying bubbles and the contagion effect between oil and stock markets: New evidence from China. *Economic Modelling* 94, 780–788.

Zivot, E., Andrews, D.W.K., 2002. Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis. *Journal of Business Economics and Statistics* 20(1), 25–44.

ANNEX 1 - DESCRIPTION OF THE DATA USED IN THE ANALYSIS

Individual commodity prices (source: IMF)

Oil: Crude Oil (petroleum), Price index, 2005 = 100, simple average of three spot prices; Dated Brent, West Texas Intermediate, and the Dubai Fateh
Gas: Natural Gas, Russian Natural Gas border price in Germany, US$ per Million Metric British Thermal Unit
Coal: Australian thermal coal, 12,000- btu/pound, less than 1% sulfur, 14% ash, FOB Newcastle/Port Kembla, US$ per metric ton
Aluminium: 99.5% minimum purity, LME spot price, CIF UK ports, US$ per metric ton
Copper: grade A cathode, LME spot price, CIF European ports, US$ per metric ton
Zinc: high grade 98% pure, US$ per metric ton
Nickel: melting grade, LME spot price, CIF European ports, US$ per metric ton
Wheat: No.1 Hard Red Winter, ordinary protein, Kansas City, US$ per metric ton
Corn: U.S. No.2 Yellow, FOB Gulf of Mexico, U.S. price, US$ per metric ton
Soy: U.S. soybeans, Chicago Soybean futures contract (first contract forward) No. 2 yellow and par, US$ per metric ton
Beef: Australian and New Zealand 85% lean fores, CIF U.S. import price, US cents per pound

Table A1. Descriptive statistics on commodity price indexes and commodity prices (1980M1-2021M12).

Series	Obs	Minimum	Maximum	Mean	Standard Deviation	Skewness	Kurtosis
Price indexes							
FoodInd[a]	372	76.04	194.1	121.9	60.20	-0.384	1.965
MetInd	504	44.16	256.2	101.3	53.69	-0.084	2.556
EneInd[b]	360	22.07	257.3	99.75	67.76	-0.656	2.244
CPI	504	40.79	146.2	92.17	28.09	-0.005	1.799
Price levels							
Oil	504	18.44	249.6	84.09	56.86	0.877	2.534
Coal	504	24.09	240.7	57.66	34.01	1.584	5.816
Gas[c]	444	1.444	32.91	5.398	4.199	1.979	10.42
Aluminium	504	918.8	3578	1712	468.1	0.778	3.325
Copper	504	1272	10308	3882	2520	0.742	2.116
Zinc	504	597.4	4381	1541	786.4	1.019	3.277
Nickel	504	3433	51783	11394	7270	1.867	8.130
Wheat	504	88.55	403.8	168.5	54.33	1.235	4.396
Corn	504	65.35	332.9	142.7	57.14	1.420	4.542
Soy	504	158.31	622.9	292.1	105.4	1.036	3.204
Beef	504	74.26	272.2	130.5	44.44	1.026	3.111
Price logarithms							
Oil	504	2.914	5.520	4.207	0.671	0.202	1.755
Coal	504	3.178	5.483	3.913	0.510	0.610	2.358
Gas[c]	444	0.367	3.493	1.461	4.250	1.255	6.286
Aluminium	504	6.823	8.182	7.409	0.265	0 .158	2.542
Copper	504	7.148	9.240	8.056	0.642	0.289	1.566
Zinc	504	6.392	8.385	7.222	0.477	0.370	1.948
Nickel	504	8.141	10.85	9.173	0.566	0.330	2.406
Wheat	504	4.483	6.000	5.081	0.296	0.489	2.882
Corn	504	4.179	5.807	4.894	0.353	0.663	2.868
Soy	504	5.064	6.434	5.619	0 .332	0.520	2.277
Beef	504	4.307	5.606	4.820	0.313	0.568	2.316

[a] 1991M1-2021M12.
[b] 1992M1-2021M12.
[c] 1985M1-2021M12.

Aggregate commodity price indexes (source: IMF)

FoodInd: Food Price Index, 2016 = 100, includes Cereal, Vegetable Oils, Meat, Seafood, Sugar, and Other Food (Apple (non-citrus fruit), Bananas, Chana (legumes), Fishmeal, Groundnuts, Milk (dairy), Tomato (veg)) Price Indices
MetInd: Metals Price Index, 2005 = 100, includes Copper, Aluminium, Iron Ore, Tin, Nickel, Zinc, Lead, and Uranium Price Indices
EneInd: Fuel (Energy) Index, 2005 = 100, includes Crude oil (petroleum), Natural Gas, and Coal Price Indices

Overall Consumer Price Index (source: US Federal Reserve)

CPI: Federal Reserve Economic Data, Economic Research Division, Federal Reserve Bank of St. Louis. CPIAUCNS Consumer Price Index for All Urban Consumers: All Items in U.S. City Average, Index 1982-1984=100, Monthly, Not Seasonally Adjusted. The **Inflation rate** is computed as the monthly growth rate of this CPI.

ANNEX 2 – COMMODITY PRICE DYNAMICS

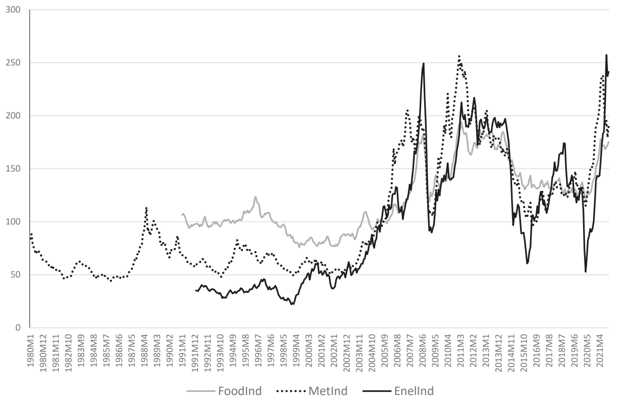


Figure A1. Commodity price indexes (2005M1=100) (1980M1-2021M12).

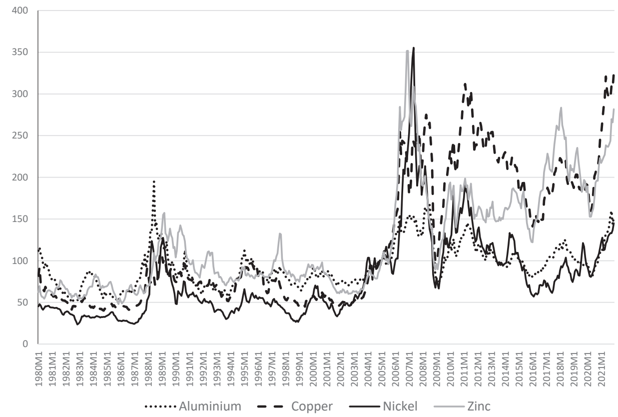


Figure A3. Metals prices (2005M1=100) (1980M1-2021M12).

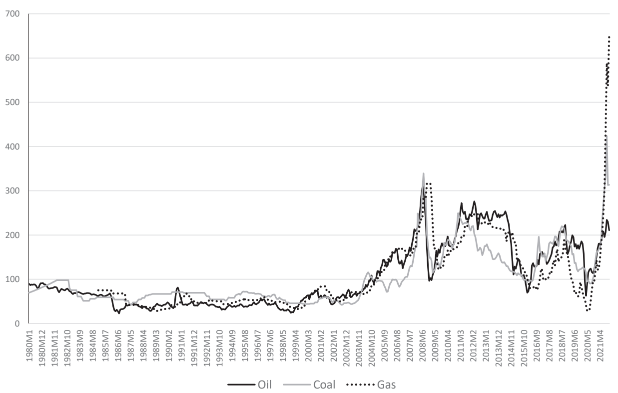


Figure A2. Energy commodities prices (2005M1=100) (1980M1-2021M12).

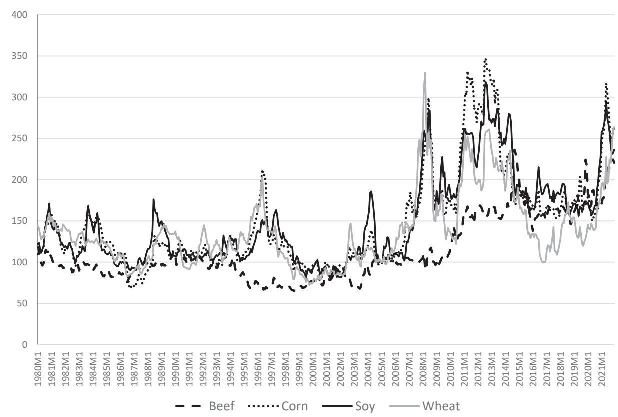


Figure A4. Agricultural commodities prices (2005M1=100) (1980M1-2021M12).

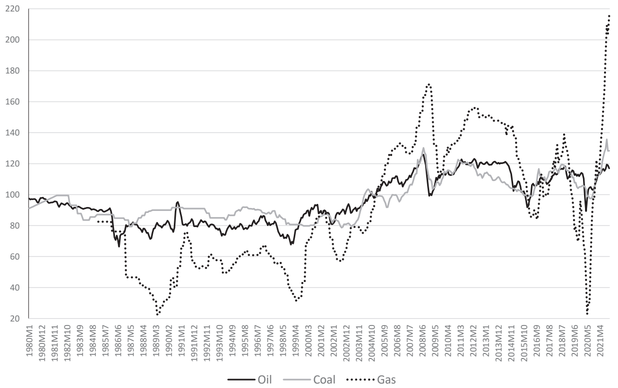


Figure A5. Logarithms of the energy commodities prices (2005M1=100) (1980M1-2021M12).

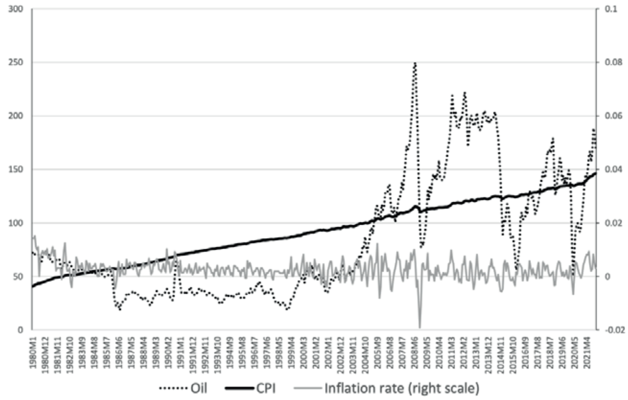


Figure A8. Oil price (2005=100), CPI (2005=100) and inflation rate (1980M1-2021M12).

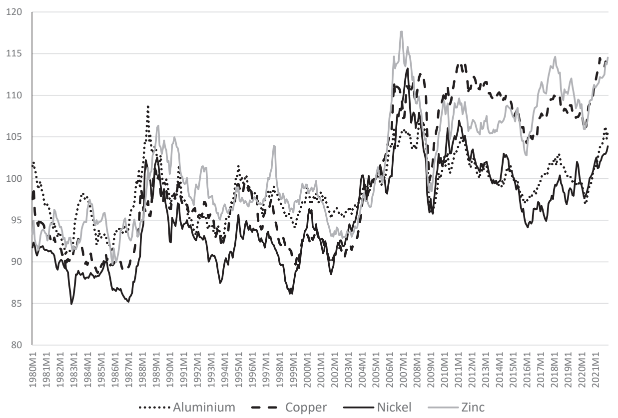


Figure A6. Logarithms of the metals prices (2005M1=100) (1980M1-2021M12).

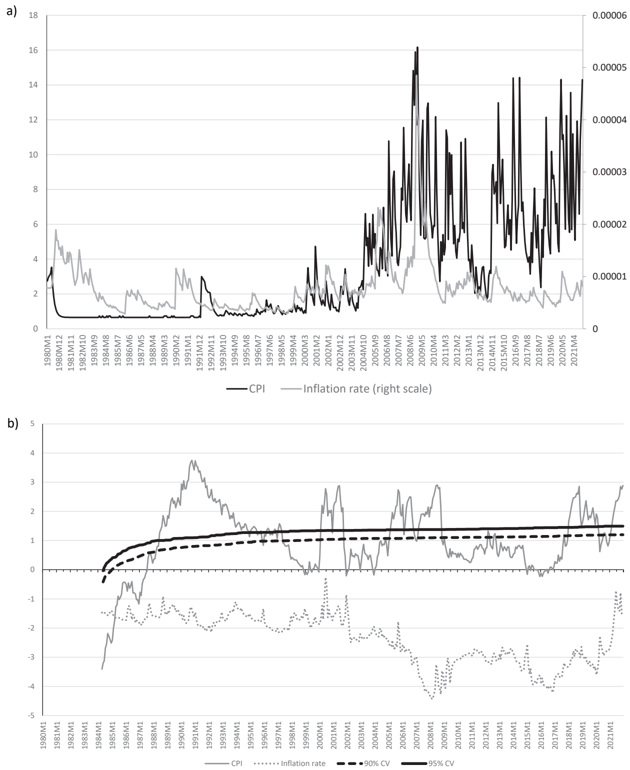


Figure A9. GARCH(1,1) model standard error in-sample prediction (a) and BSADF test for CPI and Inflation rate (1980M1-2021M12).

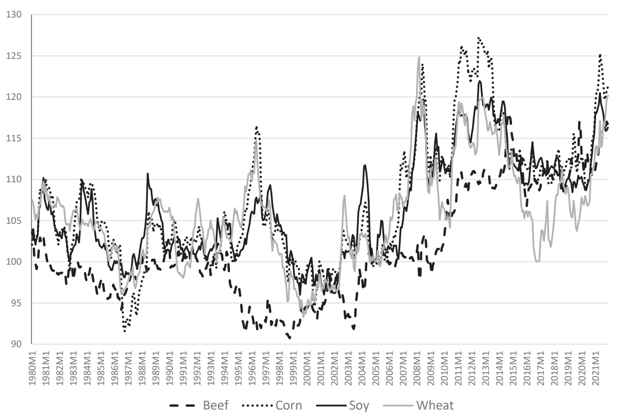


Figure A7. Logarithms of the agricultural commodities prices (2005M1=100) (1980M1-2021M12).

ANNEX 3 – UNIT-ROOT AND GRANGER-CAUSALITY TESTS WITH STRUCTURAL BREAKS

Table A2. Testing with structural breaks within an ADF specification (unit-root testing) for commodity price indexes, price levels and logarithm of levels (1980M1-2021M12).

Series	ZA (break month)[e]		CMR (b.reak months)[f]	
	Intercept	Intercept&Trend	AO	IO
Price indexes				
FoodInd[a]	-4.780	-4.932	-3.844 (1990M2*; 2006M3*)	-7.408* (1990M2*; 2006M3*)
MetInd	-3.826	-4.048	-5.176 (2005M6*; 2014M3*)	-5.406 (2004M9*; 2013M7*)
EneInd[b]	-4.199	-4.305	-4.736 (1991M2*; 2004M9*)	-4.831 (1990M11*; 2003M11*)
CPI	-3.461	-3.730	-3.079 (1992M5*; 2007M10*)	-2.570 (1985M11*; 2002M11*)
Price levels				
Oil	-4.731	-4.755	-6.299* (2005M9*; 2015M2*)	-6110* (2003M11*; 2013M5*)
Coal	-5.245* (2006M11)	-5.253* (2006M11)	-2.869 (2007M3*; 2008M1*)	-5.791* (2006M9*; 2007M6*)
Gas[c]	-2.337	-2.454	-2.462 (2004M11*; 2014M5*)	-1.718* (2003M8*; 2013M11*)
Aluminium	-4.532	-4.399	-3.447 (1987M4*; 2004M4*)	-5.603* (2004M8*; 2007M6*)
Copper	-4.471	-4.464	-3.589 (2005M6*; 2014M3*)	-4.131 (2004M4*; 2013M6)
Zinc	-4.236	-4.236	-4.209 (2005M6*; 2006M10*)	-5.614* (2004M10*; 2007M4*)
Nickel	-4.027	-4.626	-4.155 (2005M9*; 2007M1*)	-6.867 (2005M2*; 2006M4*)
Wheat	-3.663	-3.673	-3.747 (2007M4*; 2013M10*)	-5.190 (2009M11*; 2013M1*)
Corn	-4.572	-4.577	-5.119 (2009M11*; 2013M1*)	-5.688* (2009M5*; 2012M6*)
Soy	-5.091* (2006M10)	-5.102* (2007M5)	-4.749 (2007M3*; 2013M11*)	-6.061 (2006M3*; 2013M3*)
Beef	-4.009	-4.574	-4.244 (2009M5*; 2018M8*)	-4.532 (2008M9*; 2018M9*)
Logarithm of price levels				
Oil	-4.188	-4.363	-5.055 (1985M4*; 2003M9*)	-4..888 (1998M1*; 2003M11*)
Coal	-4.273	-4.597	-3.476 (2007M3*; 2008M1*)	-4..753 (2002M9*; 2005M9*)
Gas[c]	-2.598	-4.706	-4.327 (1993M10*; 2003M8*)	-6..451* (1993M11*; 2003M9*)
Aluminium	-4.349	-4.639	-4.366 (1987M4*; 2003M4*)	-5.307* (2004M5*; 2007M6*)
Copper	-4.584	-4.699	-4.392 (1987M1*; 2005M6*)	-4.820* (1985M2*; 2002M8*)
Zinc	-4.701	-4.708	-4.580 (2005M6*; 2007M1*)	-5.333 (1986M8*; 2004M6*)
Nickel	-3.958	-4.204	-4.401 (1987M1*; 2006M3*)	-4.586 (1986M2*; 2002M3*)
Wheat	-3.972	-3.969	-3.456 (2006M10*; 2013M10*)	-4.270 (2004M10*; 2013M4*)
Corn	-4.750	-4.772	-5.037 (2006M3*; 2013M10*)	-4.969 (2005M7*; 2012M4*)
Soy	-5.343* (2006M10)	-5.390* (2006M10)	-4.472 (2007M3*; 2013M11*)	-5.638* (2005M8*; 2013M3*)
Beef	-4.039	-4.886	-4.432 (1993M1*; 2009M5*)	-4.169 (2002M4*; 2008M9*)

*Statistically significant at 5% confidence level.
[a] 1991M1-2021M12.
[b] 1992M1-2021M12.
[c] 1985M1-2021M12.
[e] Zivot Andrews (ZA) unit-root test with one endogenous structural break in the intercept or in both the intercept and the deterministic trend; lags selected with AIC between 6 and 12 months; only statistically significant breaks are reported.
[f] Clemente, Montanes and Reyes (CMR) unit-root test with two endogenous breaks (mean shifts) and deterministic trend; lags selected with AIC between 6 and 12 months; AO=Additive Outlier and IO=Innovational Outlier specifications; only statistically significant breaks are reported.

Table A3. Granger causality test (χ^2) of VAR model estimates with Oil, Coal, Natural Gas and CPI as endogenous variables (1985M1-2021M12)[a,b]

	Price levels	Logarithms of price levels
Crude oil		
Coal	13.51*	8.529*
Gas	3.558	9.221*
CPI	5.138	8.354*
Structural break dummies: 2003M11; 20013M5	4.955*; 1.273	-0.069*; -0.021
Coal		
Crude oil	16.09*	8.6054*
Gas	7.41	0.01853
CPI	3.251	0.77946
Structural break dummies: 2003M11; 20013M5	2.131; -0.375	0.039*; 0.004
Gas		
Crude oil	0.739	1.253
Coal	56.59*	3.353
CPI	5.204	6.060
Structural break dummies: 2003M11; 20013M5	-0.257; -0.052	-0.034; -0.035
CPI		
Crude oil	67.25*	47.25*
Coal	17.18*	15.91*
Gas	5.573	0.876
Structural break dummies: 2003M11; 20013M5	0.067; 0.043	0.001; 0.000

*Statistically significant at 5% confidence level.
[a] The period considered depends on natural gas data availability.
[b] The VAR model specification includes a drift, a deterministic trend and lags decided on the basis of AIC.

BAE
Bio-based and Applied Economics

AIEAA
ASSOCIAZIONE ITALIANA DI ECONOMIA AGRARIA E APPLICATA

Citation: Rocchi, B., Viccaro, M., & Sturla, G. (2024). An input-output hydro-economic model to assess the economic pressure on water resources. *Bio-based and Applied Economics* 13(2): 203-217. doi: 10.36253/bae-14957

Received: July 21, 2023
Accepted: January 16, 2024
Published: July 25, 2024

Data Availability Statement: All relevant data are within the paper and its Supporting Information files.

Competing Interests: The Author(s) declare(s) no conflict of interest.

Editor: Matteo Zavalloni

ORCID
BR: 0000-0002-7545-3093
MV: 0000-0001-9315-4110
GS: 0000-0001-8578-1384

An input-output hydro-economic model to assess the economic pressure on water resources

Benedetto Rocchi[1,*], Mauro Viccaro[2,3], Gino Sturla[1]

[1] *Department of Economics and Management, University of Florence, Italy*
[2] *School of Agricultural, Forestry, Food and Environmental Sciences, University of Basilicata, Italy*
[3] *Institute of Methodologies for Environmental Analysis-National Research Council of Italy (CNR-IMAA), Italy*
* Corresponding author. E-mail: benedetto.rocchi@unifi.it

Abstract. This study develops a hydroeconomic input-output (IO) model to evaluate the pressures that economic activities exert on water resources. For a better understanding of the sectoral and total impacts, three innovations are incorporated with respect to previous literature: i) the development of a methodology for disaggregating the extended water demand (blue water plus grey water) by economic sector, ii) the use of the IO side of the model to reclassify water demand by "extracting" and "demanding" sectors, and iii) the proposition of an improved indicator of pressure on water resources based on a "feasible" measure of water supply. Empirically tested in the Tuscany region (Italy), our findings reveal significant changes in the structure of economic pressures when adopting the proposed approach. When assessing direct total water withdrawals, agriculture accounts for 61% and manufacture for 20% of regional pressures. However, when considering only the demand for water resources exposed to scarcity reclassified by demanding sectors, agriculture falls to 5% and manufacture rises to 54%. By incorporating grey water in water demand and a "feasible" measure of supply, the regional water exploitation indicator increases from 0.05 to 0.19, and can even reach 0.30 with dry hydrological conditions, beyond the threshold for moderate scarcity (0.20). The unbalance between water supply and demand worsen even more when considering the balance of surface waters only (1.16). The proposed model can support an in-depth analysis of an economy's water footprint, allowing impacts to be mapped from specific industries to particular water bodies. This information can support decisions about sustainable water management at the national and regional levels.

Keywords: input-output, extended water demand, feasible water supply, extended water exploitation index, Tuscany.
JEL Codes: C67, Q25, Q50.

1. INTRODUCTION

Input-output (IO) models have been widely used to quantify the direct and indirect water consumed by industries in order to satisfy the final demand (Velazquez, 2006; Guan and Hubacek 2008; Lenzen et al., 2013; Ridoutt et al., 2018). A typical use of input-output models extended to water

Firenze University Press | www.fupress.com/bae

resources is for structural analysis. A wide literature has been developed in the last years on the concept of water-energy-food (WEF) nexus, aiming at studying the structural interdependencies among human needs, production activities and natural resources and the related social, technological and environmental constraints (White et al., 2018; Xiao et al., 2019; Deng et al., 2020; Lee et al 2021; Meng et al., 2017). A further field of application of environmentally extended IO models is the analysis of virtual water flows among countries and the quantification of the water footprint at the regional, national and global scale (Feng et al., 2011; Duarte et al, 2016; Arto et al, 2016; Sturla et al 2023 and 2024; Wang et al., 2021).

IO models are also used to assess the water balance of the economy, comparing an estimate of water demand based on economic modelling with a measure of water supply based on hydrological data (Cámara and Llop, 2020; Garcia-Hernandez and Brouwer, 2021). Studies, however, differ on how the demand for water generated by human activities is defined. Cámara and Llop (2020), for instance, consider the net demand (withdrawals minus discharges) while Garcia-Hernandez and Brouwer (2021) consider only water withdrawals. Furthermore, these studies do not consider grey water, i.e. the water required for dilution of pollutants present in water discharges.

In a paper on North China, Guan and Hubacek (2008) use an IO model to determine an "extended" demand of water, defined as the net demand (including blue and green water) plus the water required for pollutants dilution (grey water). Grey water is estimated based on a mixing model developed by Xie (1996), using the chemical oxygen demand (COD) as an indicator of pollution. Grey water requirements (and, as a consequence, the extended demand), however, is quantified only for the whole economy. Furthermore, in modeling the interactions between the economy and the natural hydrological system, these authors do not quantify any indicator of economic *pressure* over water resources.

In literature, several indicators of pressure on water resources have been proposed. The water exploitation index (WEI) corresponds to the ratio between blue water withdrawals and natural availability net of the ecological flow (European Environment Agency, 2005). An improved version of the WEI (WEI+) subtracts returns to water bodies, therefore considering the *net* water demand (Faergemann, 2012; European Environment Agency, 2020; Casadei et al., 2020). In other studies, the water availability index (WAI) or withdrawals to availability (WTA) ratio is defined as the ratio of water withdrawals to renewable water availability (OECD, 2015; Garcia-Hernandez and Brouwer, 2021; Pfister et al., 2009). A conventional threshold value of 20% for all the mentioned indicators is used as a water scarcity criterion. This threshold has been recommended to identify the presence of some degree of water stress, while a value of 40% has been proposed to differentiate moderate from severe shortages, without any specific considerations of regulation capacity and extraction feasibility (Raskin et al., 1997; Alcamo et. al, 2000, Pfister et al., 2009, CIRCABC, 2012).

Based on this background, the objective of this paper is to develop an input-output hydroeconomic model to evaluate the economic pressure on water resources in a more comprehensive way than previous studies. The main innovations of our approach are: i) the development of a methodology for disaggregating the extended water demand (including grey water requirements) by economic sector, ii) the use of the IO side of the model to reclassify water demand by "extracting" and "demanding" sectors, and iii) the proposition of an improved indicator of pressure on water resources based on a "feasible" measure of water supply.

To calculate the grey water demand for each economic sector, a mixing model is solved that considers the capacity of surface and groundwater to degrade organic matter, not only the standard model based on the mass continuity equation of the dough (Hoekstra 2011). We use a modified version of the model proposed by Xie et al. (1996) to estimate the requirements of water for dilution by economic sector, considering that water for dilution is supplied by the hydrological system with a given level of pollution.

In our model some industries withdraw and return water directly from/to the hydrological system while others do so only through the water supply and the sewerage services. When considering only the direct withdrawals from water bodies, we refer to "extracting industries". The input-output matrix, through the intermediate flows of goods and services, allows us to reclassify the water demand by "demanding sector", that is, a new distribution of water uses that considers the direct *and* indirect pressure of economic sectors on water resources.

The indicator of pressure on water resources proposed in this study corresponds to the WEI+ indicator but including grey water also in the numerator and considering a *feasible* measure of supply as a denominator. The groundwater supply considers long-term recharge within a technical range of abstraction. The supply of surface water includes also technical (extraction capacity) and institutional (water concessions) constraints. According to our Extended Water Exploitation Index (EWEI) the feasible supply depends on hydrology conditions. The more the hydrology is distant from the average year, the more technical and institutional constraints are important.

We implement the model for the Tuscany region of Italy. Using hydrometeorological information, the water availability is determined, from which the feasible supply is estimated. The mixing model depends on water quality parameters, the effect of water availability on the COD concentration in water bodies and the water discharges from the IO hydro-economic model (two-way arrow in Figure 1). Based on the results of the mixing model (dilution water coefficients), water withdrawal and discharge coefficients and the IO regional table, the hydro economic model allows to calculate the extended water demand by extracting industry and reclassify it by demanding industry. Finally, based on the extended water demand and the feasible supply, the EWEI indicator is obtained.

The paper is organized as follows. Section 2 presents the structure of the input-output model extended to water resources, including the methodology for estimating water requirements for dilution and the reclassification of the extended demand by demanding industry. Section 3 presents the proposed pressure indicator, based on the model's output and on information about surface and groundwater availability in the region. Section 4 describes data and methods used to implement the empirical model for Tuscany. Section 5 presents the results for the reference year in terms of net and extended water demand classified by industry and water body and an assessment of the overall level of pressure on water resources in Tuscany based on the EWEI. Section 6 presents a discussion of the main results and of methodological limitations of the study. Finally, section 7 provides concluding remarks and suggestions for future research.

2. THE HYDRO-ECONOMIC MODEL

2.1. Hydro-economic water flows

Following Guan and Hubacek (2008) we consider the extended demand approach, which include the water withdrawals for productive[1] uses minus the discharges of water to the hydrological system plus the unavailable water for qualitative balance of water bodies (water requirements to dilute the pollution).

The economic system withdraws water from underground and surface sources (blue water) and from rain and soil moisture (green water). After productive uses,

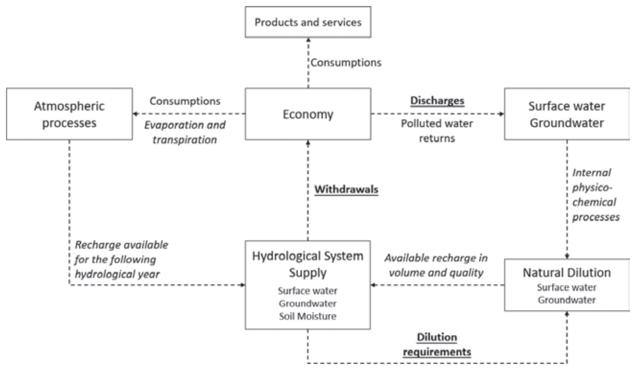


Figure 1. Scheme of the hydro-economic input-output model. Source: Own elaborations.

water can be divided into: i) water discharged to surface and groundwater, ii) water incorporated in products and consumed in services, iii) water consumptions by evaporation and transpiration into the atmosphere, and iv) water removed from the immediate water environment (Kenny et al., 2019; Macknick et al., 2012).

Figure 1 presents a schematic illustration of the water flows in the hydro-economic system. The productive system extracts water from the hydrological system supply (*withdrawals*), that is, surface water, groundwater, precipitation and soil moisture (the latter two components associated with agriculture). A part of this water is consumed (goods and services, evaporation and transpiration); the remaining part is discharged with pollution to groundwater and surface water (*discharges*). By means of physical-chemical processes and fresh water from the hydrological system reserved for quality restoration (*dilution requirements*), the restored water is available again for use in the production system (in volume and quality). Water that returns to the atmosphere is not considered as a recharge within the reference period of the model (one year).

It is important to note that the concept of net water demand (withdrawals minus discharges), widely used in the literature to estimate the water exploitation index (WEI+) (Faergemann, 2012; European Environment Agency, 2020) considers only the *volume* of water. The concept of extended water demand used in the present study to calculate the extended water exploitation index (EWEI), conversely, considers both water volume and water *quality*.

2.2. Input-output hydro-economic model

We consider an economic system with n productive sectors (industries) and a water system with m water

[1] In this study, we are interested in water used for production. That is, we assume that water for domestic uses is provided by the water supply industry. Actually, there are also direct withdrawals by households from groundwater and surface water bodies whose relevance, however, depends on the case study. In Tuscany, this component of the household demand for water does not exceed 3% of total and has not been considered in the analysis.

sources (or water bodies) to build an environmentally extended IO model (Miller and Blair, 2009).

Let A_d[2] be the matrix of coefficients that represents the structure of intermediate consumptions per unit of output of production activities, calculated from the domestic flows input-output table. The total production of the n industries can be calculated from the following equation:

$$x = (I - A_d)^{-1}y \tag{1}$$

where x is the vector of gross output of the industries, y is the vector of the final demand and I is the unit matrix. In the hydro-economic approach, the model is expanded to link the level of activation of each industry with exchange flows between production activities and the water bodies composing the hydrological system. Let:

f_k be the $(n \times 1)$ vector of the unit water withdrawal coefficients (m^3/€) of industries from the water body k.

r_k be the $(n \times 1)$ vector of the unit water discharge coefficients (m^3/€) of industries to the water body k.

w_k be the $(n \times 1)$ vector of the unit water for dilution requirement coefficients (m^3/€) of industries for the water body k.

The extended water demand $(n \times 1)$ vector e_k for the water body k, disaggregated by industry, is given by:

$$e_k = (\widehat{f_k} - \widehat{r_k} + \widehat{w_k})\ (I - A_d)^{-1}y,\ k = 1,\ldots,m \tag{2}$$

The hat symbol indicates the diagonalization of the vector. By repeating the operation for the m bodies of water considered in the model it is possible to constitute the $(n \times m)$ matrix ED representing the extended water demand of the n productive sectors from the m bodies of water:

$$ED = \hat{x}(F - R + W) \tag{3}$$

where the $(n \times m)$ matrices F, R and W represent respectively the withdrawal, discharge and dilution requirements coefficients by industry and water body.

The total extended demand of water associated with the entire economy, by water source, can be represented by the $(m \times 1)$ vector TED:

$$TED = (F - R + W)'x \tag{4}$$

where the symbol ' represents the transposed matrix. The *net* water demand (ND) can be calculated in an analogous way simply excluding from equations (2) to (4) the terms referring to water requirement for dilution (vectors w_k and matrix W).

2.3. Water requirements for dilution

In this section we show how the $(n \times 1)$ vector w_k, which was defined in the previous section, is calculated to determine the water requirements for pollutants dilution by economic sector and by water body k.

We use a mixing model considering the chemical oxygen demand (COD) parameter based on the model developed by Xie (1996) (Xie-Model, hereafter) and used by Guan and Hubacek (2008) to estimate the extended demand for the whole economy. This model considers that pollutants are diluted as a result of three effects: mixing with fresh water with a lower concentration, chemical reactions before entering the water bodies and chemical reactions after entering the water bodies. The first component refers to the surface waters and groundwater existing in the discharge areas and the additional water required when this is not enough. This additional water corresponds to grey water. (For more details see Appendix A). In this work, we improve the Guan and Hubacek's approach as follows:

– the water requirement for dilution associated with each production sector is estimated (only for the whole economy in the Xie-Model);
– the dilution water is considered to have a COD concentration similar to the water available for productive use (COD equal to zero in the Xie-Model);
– the worst case is assumed, i.e., when there is no availability of water in the receiving bodies (total natural supply in the Xie-Model).

Let assume that vector w_k comes from a $(m \times n)$ matrix W whose elements w_{kj} represent the coefficients of water for dilution (m^3/€) referred to the body of water k and the industry j:

$$w_{kj} = \frac{u_{kj}}{x_j}$$

where, u_{kj} (m^3/year) is the element of the $(m \times n)$ matrix U representing the water required for dilution (including losses) in the water body k by the economic sector j, while x_j (€) corresponds to the total output of sector j.[3]

[2] For the purposes of this paper, the matrix of direct coefficients for domestic production is calculated following the methodology of Weber et al. (2008). This method assumes that each economic sector and final demand category uses imports in the same proportions.

[3] For the case of this study $m = 3$ (groundwater, surface water and soil moisture), however, the third column of the matrix W (and the matrix U) corresponds to zeros, since the water for dilution is only required to purify water discharged in surface and groundwater bodies.

The following expression (mixing model) is used to estimate u_{kj}:

$$u_{kj} = \left[\frac{k_{2_k} \cdot c_{p_{kj}} - c_{s_k}}{k_{1_k} \cdot c_s - c_{0_k}}\right] \cdot q_{p_{kj}} \quad (6)$$

where:

k_{1_k}: total reaction rate of pollutants after entering the water body k;

k_{2_k}: pollution purification rate before entering the water body k;

$q_{p_{kj}}$: discharges into the water body k associated with industry j;

$c_{p_{kj}}$: COD concentration in the discharges to the water body k associated with economic sector j;

c_{s_k}: standard COD concentration in water body k;

c_{0_k}: COD concentration in water body k.

The standard COD concentration c_{s_k} refers to a low level of pollution associated with good water quality in water bodies. The water used for dilution has a concentration equal to that of the receiving water bodies (c_{0_k}).

Note that in equation (6) the discharge corresponds to $q_{p_{kj}} = r_{kj} \cdot x_j$, obtained through the hydro-economic input-output model.

The COD concentration in water bodies is a parameter that depends on the hydrological system (c_{0_k}), decreasing when water availability is higher and increasing when it is lower. In the case of this study, the concentration associated to an average availability is considered in the base analysis and modified to calculate the water exploitation index in case of dry and wet hydrology.

Appendix A (Supplementary Materials) presents the development of the mixing model by explaining in detail the differences between our study and the Xie-Model.

2.4. Reclassification by demanding sectors

The input-output matrix, through the intermediate flows of goods and services, allows to reclassify the net demand and the extended demand of water by "demanding sectors", that is, according to a new distribution that considers the direct and indirect pressure of each economic sector on the different water bodies of the hydrological system.

It is possible to rewrite equation (2) based on (1),

$$e_k = (\widehat{f_k} - \widehat{r_k} + \widehat{w_k}) \cdot x,\ k = 1,\ldots,m \quad (7)$$

The coefficients in vectors f_k, r_k and w_k are different from zero only for production activities that actually withdraw and return water from/to water bodies. Despite all production activities require and discharge water (although to a different extent), the withdrawals and the discharges of water from/to different bodies of the hydrological system are actually carried out only by a limited number of industries (*extracting sectors*). For example, the largest part of service activities purchase water from the water supply sector and discharges water throughout the sewerage service sector. Referring to equation (7) would provide only a partial view of the interdependencies existing between the economy and the hydrological system.

It is of interest to know the use of water reclassified by *demanding sector*s. This was done adding to the total direct use of water of each sector the "virtual" demand of water from other sectors associated with the purchase of intermediate inputs; and subtracting the "virtual" sales of water to other sectors *via* the supply of intermediate inputs as well.

The vector of "virtual" water sales associated with water source k is,

$$s_k = (\widehat{f_k} - \widehat{r_k} + \widehat{w_k})\ A_d x \quad (8)$$

The vector of "virtual" water purchases associated with water source k is,

$$p_k = \hat{x}A'_d(f_k - r_k + w_k) \quad (9)$$

Thus, the reclassified water extended demand vector ($\tilde{e}_k$) for the water source k can be written combining equations (7), (8) and (9).

$$\tilde{e}_k = e_k - s_k + c_k = (\widehat{f_k} - \widehat{r_k} + \widehat{w_k})(x - A_d x) + \hat{x}A'_d(f_k - r_k + w_k) \quad (10)$$

Repeating this procedure for each of the m water sources, the ($n \times m$) matrix *RED* is obtained, representing the extended demand from the m bodies of water reclassified by demanding sector. The reclassified extended water demand (n x m) matrix *RED* can be written as:

$$RED = (\hat{x} - \widehat{A_d x} + \hat{x}A'_d)(F - R + W) \quad (11)$$

Following a similar procedure, it is possible to find the expressions for the reclassified *net* demand vector ($\tilde{d}_k$) for the water source k and the ($n \times m$) matrix *RND* representing the extended demand from the m water bodies reclassified by demanding sectors.

3. AN INDICATOR OF ECONOMIC PRESSURE ON WATER RESOURCES

3.1. Water supply

In the previous section, the economic demand for water has been defined. An analysis of economic pressures on water resources must also consider water availability. Most of the literature has used the natural water supply net of a minimum ecological flow (Faergemann, 2012; European Environment Agency, 2020; OECD, 2015; García-Hernández and Brouwer, 2021; Pfister et al., 2009). However, it is not realistic to assume that it is always possible to extract all available surface and groundwater. In practice, in addition to environmental restrictions there are technical and institutional constraints. In the following sections, the natural water supply is characterized based on the hydrological components and a way to correct the natural supply is proposed based on technical and institutional factors.

3.2. Natural supply

Our water supply indicator considers blue water supply and does not include green water (precipitation and soil moisture). To determine the water supply it is necessary to know the components of the hydrological simplified regional balance (Braca et al., 2021, 2022) for a year t, which are precipitation (P_t), evapotranspiration (E_t), groundwater recharge (I_t), runoff (R_t) and the variation in soil moisture (ΔV). The balance equation is:

$$P_t = E_t + I_t + R_t + \Delta V_t \qquad (12)$$

The annual natural supply of groundwater and surface water (S_t^{nat}) is equal to the sum of the recharge of the aquifers and the runoff:

$$S_t^{nat} = I_t + R_t \qquad (13)$$

This natural supply is variable from year to year, so a long-term natural supply is defined, based on long-term groundwater recharge and average runoff.

$$S_t^{nat} = I + R \qquad (14)$$

For the construction of the WEI (European Environment Agency, 2005), WEI+ (Faergemann, 2012; European Environment Agency, 2020), WTA (OECD, 2015; Pfister et al., 2009) and WAI (Garcia-Hernandez and Brouwer, 2021) indicators, a version of the long-term natural supply net of the environmental requirements, i.e. the ecological flow (EF), is used. In our notation we define the natural supply with ecological flow as:

$$S = I + R - EF \qquad (15)$$

3.3. Feasible supply

We define a "feasible" water supply taking into account environmental, technical, and institutional limitations to natural water supply. The management of renewable but limited resources must consider these aspects that constrain the use of water by the economic system. In the following, the feasible supply is characterized in a detailed and formal way.

The technical, institutional, and environmental limitations that characterizes the feasible supply for surface water are the following. First of all, although rivers are renewed year after year, not all the runoff of water can be used for economic purposes. On one hand, in the years of high flow, the possibility to capture and accumulate water (hydraulic works) is limited; moreover, it could not be possible to extract all the natural supply of water because the active concessions do not allow it. Second, it is not environmentally sustainable to extract all available water as a minimum "ecological" flow is required for the aquatic ecosystem to continue to thrive and provide their services. A "feasible" measure of water supply must take into account that it is possible to withdraw water only up to a certain maximum quantity.

The proposed definition of a feasible supply of surface water is based on the following assumptions:

- the maximum amount of surface water extraction is defined by the sum of the maximum withdrawals allowed by current concessions; the assumption we make here is that the concessions have been efficiently awarded, considering all technical and hydrological aspects;
- the surface water supply is considered to be limited by a minimum "ecological" flow, as a constraint to environmental sustainability;
- the maximum concessions levy is defined as $M\bar{R}$, where M is a factor not necessarily less than 1 and $\bar{R}$ is the average annual runoff;
- the minimum ecological flow is defined as $E\bar{R}$, where $E \in (0,1)$;
- the "feasible" annual average runoff is strictly lower than the $\bar{R}$ value.

Summing up the value of R_t^{feas} is:

$$R_t^{feas} = \left\{ \begin{array}{cc} R_t - ER & if \ \ ER < R_t < MR + ER \\ M\bar{R} & if \ \ R_t > M\bar{R} + E\bar{R} \\ 0 & if \ R_t < E\bar{R} \end{array} \right\} \qquad (16)$$

The technical, institutional, and environmental limitations that affect the feasible supply of groundwater are different. Groundwater corresponds to a stock that varies according to the annual recharge; consequently, the extraction annually available depends more on the average annual top-up than on the top-up of the year. Unlike surface water, if the recharge in a given year is low, it is still possible to extract a larger quantity (reservoir effect); conversely, when the recharge is high, there are technical and institutional limitations to extraction. The feasible supply can be equal to the *average* recharge (which ensures sustainability, i.e., a non-decreasing groundwater stock); however, there are some variations that depend on the stock of the resource and the amount of water that infiltrates during the year. In a scenario in which there is no over-exploitation of the aquifers, that is, there are no large variations in the stock, it makes sense to assume that sustainable extraction will be around the average recharge, that is, it will be a little lower in a rainy year and a little higher in a dry year. In general, groundwater concessions are awarded for a slightly higher value than the annual sustainable recharge, since there are years in which it would not be possible to extract the *actual* recharge (due technical limitations, especially for small users) and other years when it is possible to extract more than the *average* recharge.

The proposed definition of a feasible supply of groundwater is based on the following assumptions:

- the sum of the groundwater concessions (D) is the feasible upper supply limit;
- the difference between the sum of the concessions and the average annual recharge (D - $\bar{I}$), defines a share B by which the average recharge can be increased to calculate the feasible supply ($B = \frac{D-I}{\bar{I}}$) where $B \in (0,1)$ and I is the average annual recharge;
- the feasible groundwater supply (that can be drawn in one year) will be in the range $[\bar{I}(1 - B), \bar{I}(1 + B)]$; Summing up the value of I_t^{feas} is:

$$I_t^{feas} = \left\{ \begin{array}{ll} \bar{I}(1-B) & if\ \ I_t < \bar{I}(1-B) \\ \bar{I}(1+B) & if\ \ I_t > \bar{I}(1+B) \\ I_t & if\ \ I \in [\bar{I}(1-B), \bar{I}(1+B)] \end{array} \right\} \quad (17)$$

Consequently, if the distribution of I is symmetrical around the average, the feasible annual average supply will be equal to the value $\bar{I}$.

The feasible supply for a year t (FS_t) can be defined as:

$$FS_t = I_t^{feas} + R_t^{feas}$$

The long-run feasible supply (FS) corresponds to the average over time (N years):

$$FS = I_t^{feas} + R_t^{feas} = \frac{1}{N}\sum_t^N I_t^{feas} + \frac{1}{N}\sum_t^N R_t^{feas}$$

This correction made to the natural supply of water allows for a more precise approach to the availability of water in the study region. The formulation considers that a series of N years of the hydrological components is available. The longer the series, the more representative of the long-term this defined feasible supply will be. In the next section, an indicator of pressure on water resources is defined considering the proposed measure of water availability.

3.4. An extended water exploitation index

We propose a new indicator of economic pressure on water resources, the Extended Water Exploitation Index (EWEI), comparing the extended demand for groundwater and surface water, and the feasible supply. It basically corresponds to the WEI+ indicator (ratio of net demand to natural supply) but including grey water and considering environmental, technical and institutional constraints in the use of water.

Using equations (3) and (19) the EWEI can be written as:

$$EWEI = \frac{i\sum_{k=1}^{2}\left(\widehat{f_k} - \widehat{r_k} + \widehat{w_k}\right)' \cdot x}{I^{feas} + R^{feas}} \quad (20)$$

where i is a ($1 \times n$) vector of ones, which allows summing the extended water demand associated with each economic sector. The sum considers groundwater and surface water, k={1,2}.

Considering equation (1) the EWEI can be expressed in terms of the final demand:

$$EWEI = \frac{i\sum_{k=1}^{2}\left(\widehat{f_k} - \widehat{r_k} + \widehat{w_k}\right)' (I - A_d)^{-1} y}{I^{feas} + R^{feas}} \quad (21)$$

The other indicators proposed in the literature assume a perfect substitutability between groundwater and surface water, which is not necessarily true. For this reason, in our analysis we also consider the EWEI separately for groundwater and surface water[4].

[4] The EWEI can vary from 0 to values not necessarily lower than 1, that would correspond to an extended demand equal to the feasible supply. As the index is calculated for a whole region and with reference to a one-year period, its value is likely to be largely lower than 1. The intra-annual variability of natural supply as well as the uneven spatial distribution of water resources, however, suggest that situations of water scarcity could exist also in presence of low values of the annual, regional index. This justify the value of the conventional scarcity thresholds adopted in environmental studies (largely lower than 1) and described in section 1.

4. CASE STUDY

The proposed model was empirically implemented for the Tuscany region (Central Italy). The regional Government as well as other agencies involved in various ways in the monitoring and management of regional water resources made available a wide set of data sources to reconstruct the following components of the model: i) an input-output table of the Tuscan economy (reference year 2017) properly disaggregated; ii) the water withdrawals (classified by water body) by production activity existing in Tuscany (NACE classification); iii) the industries' water discharges to the hydrological system by water body and by level of water quality; iv) the regional hydrological balance and the feasible supply of water.

In what follows we provide a summary of the main data used and the assumption made in building the model. A detailed documentation of the empirical implementation can be found in Appendix B (Supplementary Materials).

4.1. The input-output table of Tuscany.

The model is based on the input-output table (year 2017) of the Tuscan economy developed by the Regional Institute for Economic Planning of Tuscany. The classification of production activities (56 industries) already represented, as separate industries, some of the key sectors in the exchange water flows between the economy and the environment (water supply services, sewerage services, electricity power production and other activities with an intensive use of water). Agriculture, an industry that makes an intensive use of water resources for both crop irrigation and livestock rearing, was disaggregated into 8 subsectors corresponding to General Farm Types defined by the EU Regulation 1242/2008 (farms specialized respectively in fieldcrops, horticulture, permanent crops, grazing livestock, granivores, farms with mixed cropping, mixed livestock, mixed crops-livestock).

4.2. Water withdrawals and discharge coefficients

For each industry, water requirements and discharge coefficients were estimated using different bibliographic and research data.

For agriculture, the estimation of irrigation needs was first developed at the municipal level, considering the specific irrigation requirements of each group of crops based on the climate conditions of each municipality. The total withdrawals at the municipal level were divided between underground (wells and springs) and surface sources of supply (reservoirs, lakes, rivers and streams) using the information available in the 2010 General Agricultural Census at the municipal level. The two sources of supply are substantially balanced at the regional level, representing respectively 49.6% and 50.4% of total withdrawals. The estimates of water withdrawals by crop typology were then reclassified into the eight sub-sectors of agriculture using the data of the census of Tuscan agriculture[5]. The discharge coefficients were quantified as a share of water withdrawals. This amount depends on losses due to inefficiency of irrigation systems (30% of total withdrawals) and natural losses of soil moisture by evaporation (discharges to the atmosphere). Natural losses were quantified as a percentage of green water withdrawals, based on technical coefficients from literature. We assumed that the whole amount of discharges due to inefficiency of irrigation systems returns to ground water bodies.

The estimation of water use coefficients for livestock production activities was based on technical literature about the needs of water per head of livestock per day. Specific coefficients by species and typology of livestock unit (age, production type) were applied to the composition of the regional herd. The estimated total consumption was then distributed among the different FTs based on their share in the rearing of Livestock Units according to standard results from the FADN public database. Discharges were quantified as a fixed proportion of withdrawals (13%) and assumed to be returned only to groundwater bodies.

For the estimation of the water withdrawal and discharge coefficients in the water supply industry, the information on water billed in the region for the year 2016 was used. Secondary data published by ISTAT (2019b) were used to disaggregate water withdrawals between ground and surface sources. The discharges correspond to water losses in the distribution network; we assumed that all of these losses are discharged to groundwater, constitute groundwater recharge and are not contaminated.

For the production of the electricity sector, all the existing generators in Tuscany and their annual energy production, for the year 2018, were considered at the municipality level (GSE, 2022). Water consumption corresponds mainly to evaporation in hydroelectric, thermoelectric and geothermal power plants, and was considered as a discharge to the atmosphere. Total withdrawals and discharges were considered to be from and towards surface sources.

Water requirements for manufacture activities have

[5] Details are provided in Supplementary materials, Appendix B.

been quantified using non-published national data provided by ISTAT. Starting from the water withdrawals coefficients of the Italian economic activities provided by ISTAT, average coefficients were obtained according to the regional composition of the 29 aggregated manufacturing sectors represented in the IO table, using the permanent census of manufacturing activities. The implicit assumption is that, different from agriculture, the average water requirements of manufacture are not affected by location. Water discharge coefficients were calculated using information from the Exiobase database. Ratios and shares for Italian manufacturing activities resulting from Exiobase were applied to the estimated water withdrawals by industry. The distribution of water extraction coefficients between groundwater and surface water was based on secondary data and reasonable *ad hoc* assumptions.

4.3. Quality of discharged water and mixing model

Water quality is measured based on the chemical oxygen demand (COD, in mg/L). This parameter was assigned to water returned by macro-sectors discharging water directly to water bodies: agriculture, manufacture and sewerage. The Water Supply Industry is not considered because its returns are of water with low COD concentration (losses in aqueducts). A methodology was defined for each macro-sector to properly characterize the quality of its discharges.

For the reaction rate of pollutants after entering the water body parameter (k_{1_k}) in equation (6), we consider a value (dimensionless) of 2.80 and 3.64 for groundwater and surface water, respectively. For the pollution purification rate before entering the water body parameter (k_{2_k}) we consider a value (dimensionless) of 0.82 and 1.00 for groundwater and surface water, respectively (Guan and Hubacek, 2008).

The standard COD concentration in water bodies (c_{s_k}) is considered equal to 20 mg/l the value for which waters are classified as unpolluted and can be used without prior treatment (Rossi and Benedini, 2020). The COD concentration in water bodies (c_{0_k}) is assumed to be equal to the standard COD concentration for an average hydrological year. In the sensitivity analysis for wet and dry hydrological years, it is assumed a value of 17.5 mg/l and 22.5 mg/l, respectively.

4.4. Hydrological Balance and natural supply

Starting from the information on the hydrological balance for Tuscany provided by ISTAT, the average natural supply of surface and groundwater has been calculated as the sum of surface water, groundwater and rainfall directly captured by the agriculture sector. Regarding the feasible supply, the total volume of surface water concessions registered by the Regional Hydrological Service (SIR, 2021) corresponds to 2,473 mm^3. This amount, however, is about 70% of the total, as many of the concession's records do not include information on the volume. A maximum value of 3,636 mm^3 has been estimated by Venturi (2014). The average annual runoff is 3,802 mm^3, thus the value of parameter M for the calculation of the feasible surface water supply corresponds to 95.6% (3,802 mm^3).

For the ecological flow, a value of E=20% is considered. This means that surface water bodies will always show a minimum flow rate equivalent to 20% of the average annual flow. This is a rather conservative value (Rossi and Caporali, 2021).

The maximum value of the groundwater concessions is 4,704 mm^3, consistent with the interannual regulation of water supply, while the average annual recharge is 4,155 mm^3 (SIR, 2021). Hence, to quantify the groundwater feasible supply, a value of $B = \frac{D-\bar{I}}{\bar{I}} = \frac{4{,}704-4{,}155}{4{,}155} =$ 13% is considered.

5. RESULTS

5.1. Withdrawals and Discharges

The volume of water withdrawals and discharges by water-extracting macro-sectors (direct or "not reclassified" water use) is shown in figure 2. The total volume of water withdrawn by the Tuscan economic system considering all sources (groundwater, surface water and soil moisture) corresponds to 2,043 mm^3. The total volume of discharges is equal to 685 mm^3 (33% of withdrawals), with Sewerage services representing about 37% of total. The total *net* demand (withdrawals minus discharges) is equal to 1,359 mm^3, corresponding to the volume of water incorporated into products. Agriculture, the only sector using green water, represents about 86% of total net demand.

The exclusive use of green water by agriculture is reflected also in the distribution of the net water demand by water source (figure 3). The soil moisture (987 mm^3) represents the 73% of total, with groundwater (221 mm^3, 16%), surface water (151 mm^3, 11%) playing only a minor role.

Figure 4 shows the net demand reclassified by demanding macro-sectors and divided by water source. Services, for example, which neither directly extract nor discharge water from/to water bodies, account for a

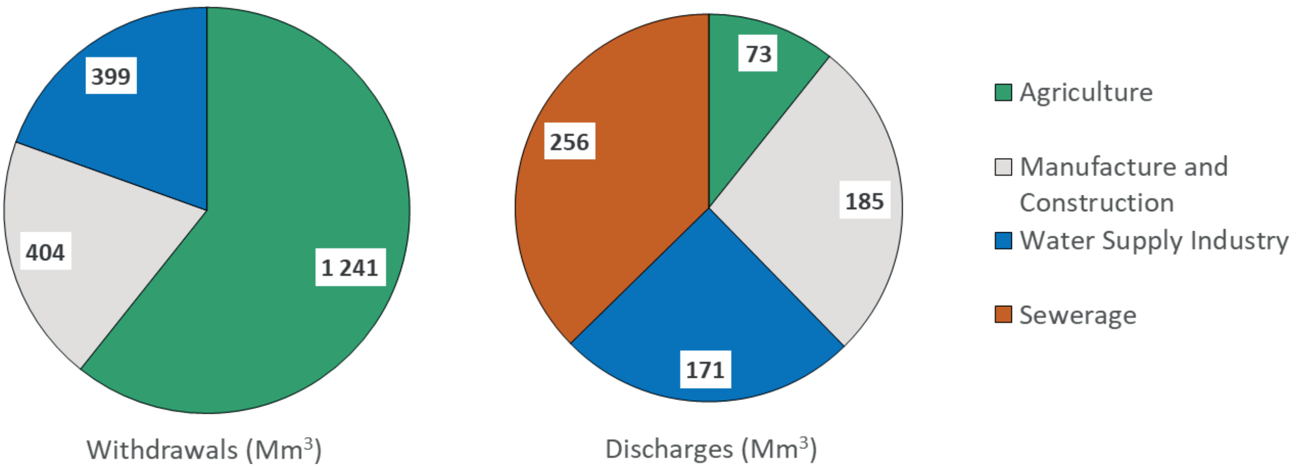


Figure 2. Water withdrawals and discharges by macro sector. Tuscany, 2017 - mm^3. Source: Own elaborations.

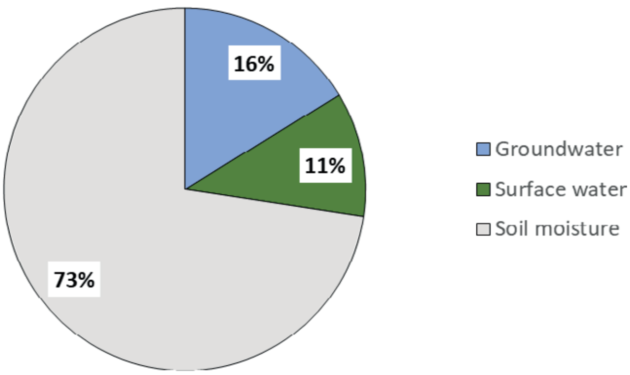


Figure 3. Net water demand by water source. Tuscany, 2017 - mm^3. Source: Own elaborations.

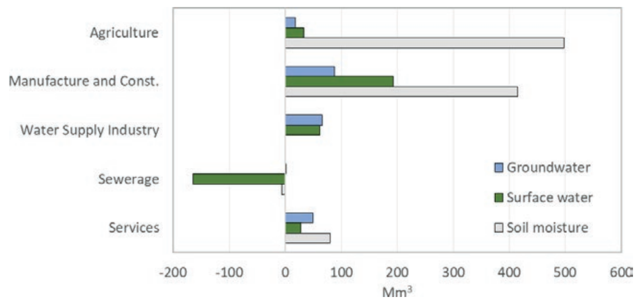


Figure 4. Net water demand by demanding macro sector and by water source. Tuscany 2017 - mm^3. Source: Own elaborations.

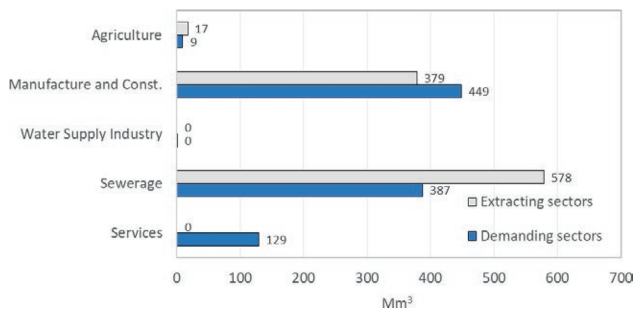


Figure 5. Water for dilution by extracting and demanding macro sector. Tuscany 2017 - mm^3. Source: Own elaborations.

reclassified net demand of 158 mm^3, since they purchase both water (from the water supply sector) and other inputs from extracting sectors. The component of the net demand supplied by the soil moisture is now distributed among different production activities, with manufacturing "indirectly" using a relevant share of green water.

5.2. Water for dilution and extended demand

Different from Guan and Hubacek (2008) the demand of water for dilution has been calculated for each industry separately. Of the total demand of grey water (974 mm^3), 17 mm^3 accrue to Agriculture (2%), 379 mm^3 to Manufacturing and Constructions (39%) and 578 mm^3 to the Sewerage sector (59%). The Water Supply industry discharges water with standard quality while Services discharges water through the Sewerage network.

The breakdown of grey water by industry allows for its reclassification by demanding sector. Figure 5 compares direct and reclassified water requirements for dilution by macro-sector. Services increase from zero to 129 mm^3 in the reclassified case, accounting for a share of grey water requirements of Sewerage services and of other industries from which it purchases inputs. Also Man-

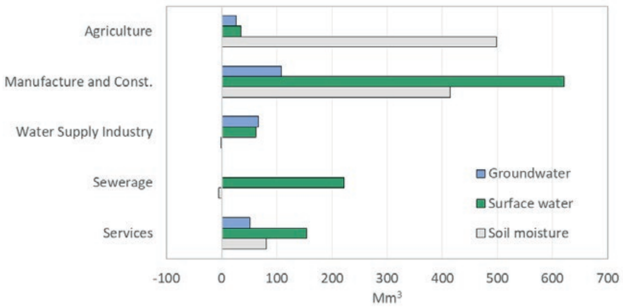


Figure 6. Extended water demand by demanding macro sector and by water source. Tuscany 2017 - mm^3. Source: Own elaborations.

Table 1. Economic pressure of the economy on water resources. Tuscany, 2017 – mm^3 and pressure indicators.

	Total	Ground-water	Surface water
Net water demand (mm^3)	372	221	151
Extended water demand (mm^3)	1 346	252	1 094
Natural supply minus ecological flow (mm^3)	7 197	4 155	3 042
Feasible supply (mm^3)	7 030	4 155	2 875
WEI+	0.052	0.053	0.05
EWEI	0.191	0.061	0.381

Source: Own elaborations.

ufacturing increases its demand for grey water (from 379 to 449 mm^3).

Grey water is a major component of water demand of Tuscany. The total *extended* water demand (total net demand plus total water for dilution), is equal to 2,333 mm^3 (+72% compared to the net demand). A prominent role is now played by surface bodies (1,094 mm^3) that supply 47% of water. Groundwater (252 mm^3) and soil moisture (988 mm^3) supply the extended demand for 11% and 42% respectively.

Figure 6 shows the extended water demand classified by demanding sectors and water body. Manufacturing is the main user of water resources, accounting for 1,144 over 2,333 mm^3 (49%) of the extended demand, mostly relying (54%) on surface bodies.

A complete breakdown of the components of net and extended demand reclassified by demanding sector for the 56 industries represented in the IO is available in Appendix C (Supplementary Materials).

5.3. Economic pressure on water resources

The extended demand for water for the reference year includes also water requirements supplied by soil moisture to agriculture (green water). To assess the pressures of the economy on regional renewable resources, only the components of demand supplied by surface and ground water bodies (blue and grey water) are considered. In this section the extended demand of groundwater and surface water is compared with the corresponding *feasible* supply.

Table 1 provides some summary results for Tuscany. The regional extended demand is equal to 1,346 mm^3. The natural supply corresponds to 7,958 mm^3. The ecological flow corresponds to 761 mm^3. The feasible supply amounts to 7,030 mm^3, about 88% of the natural supply; the reduction is due to the constraints on supply associated with surface waters.

The pressure indicator EWEI proposed in this study is compared with the standard indicator WEI+, considering only net demand and the natural supply net of the ecological flow.

In the reference year of the analysis (2017) the groundwater recharge component was included in the interval assuring the maintenance of the groundwater stock in the long-run. Therefore, the feasible supply of groundwater is equal to the natural supply. In the case of surface water, constraints in water exploitation reduce to 2,875 mm^3 the "feasible" supply (compared to 3,042 of natural supply). The results show that at the regional level the overall use of water generated by the economy is still compatible with the available resources, also when natural, technical, and institutional constraints to water use are taken into account. When the thresholds proposed in the literature for these indicators are considered (Raskin et al., 1997; Alcamo et. al, 2000; Pfister et al., 2009; CIRCABC, 2012), the WEI+ is well below the 20% limit. However, when considering the EWEI indicator, the situation in Tuscany appears to be close to a moderate scarcity.

As explained in section 3, the denominator of the EWEI ratio depends on the values assumed by the hydrology in the average year. However, the components of the hydrological balance are random variables that can largely differ from the mean values both upward and downward. It could be interesting to assess what would be the pressure on water resources when natural components of the balance show extreme values. Figure 7 shows the results of such a sensitivity analysis, comparing the values assumed by the EWEI with a feasible supply calculated with reference to a mean hydrological situation and to two extreme cases corresponding to the years with the best (2010) and the worst (2007) hydrological supply in the reference period (1970 – 2010).

When considering the standard thresholds, it is interesting to note that in a dry year, the EWEI value

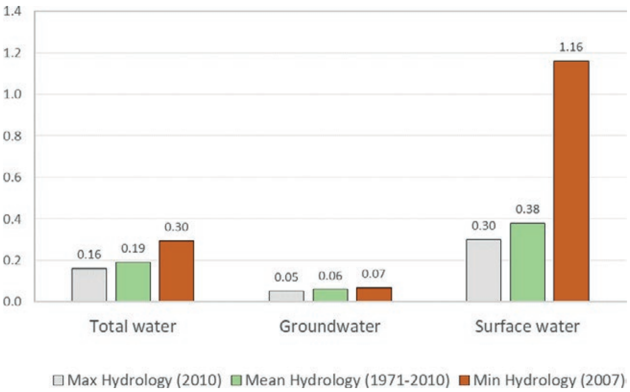


Figure 7. Sensitivity analysis of EWEI indicator. Mean hydrological balance vs. extreme years. Source: Own elaborations.

(0.3) would indicate that Tuscany is in moderate scarcity (0.4 being the limit for *severe* scarcity). Despite this value of the EWEI still implies a safety margin between the extended demand and the feasible supply, it should be considered that the regional mean annual value of the EWEI hides a wide variability of the hydrological balance at the sub-regional level, with possible critical local situations. Moreover, the breakdown by water sources shows relevant differences between ground and surface water. The former faces a quite stable pressure, due to the reservoir effect of the stock. Conversely, in the case of surface water, a worsening of the hydrological scenario could lead to a relevant increase of pressures, with a surface water EWEI almost three times greater (1.16 vs. 0.38 for the average hydrology scenario). In a critical year the extended demand of surface water in Tuscany would exceed by 16% the feasible supply.

6. DISCUSSION

The model proposed in this study allows a more comprehensive understanding of sectoral economic pressures on water resources. Unlike previous studies, which only consider the sectoral disaggregation in blue water uses, this study also allows the identification of grey water associated with each economic activity. Along the same lines, this study makes it possible to evaluate the direct and indirect pressures on the different bodies of water, through a reclassification by demanding sectors based on the IO model. Furthermore, the flexibility of the proposed methodology allows evaluating changes in the pressure structure when considering different approaches.

The case study is eloquent regarding the significant changes that the pressure structure can present. When considering withdrawals, a classification of demand by extracting sector and all water sources in the quantification of supply, agriculture represents 61% of regional pressures, manufacturing 20%, and the water supply industry 19%. On the other hand, when considering the extended demand, a classification of demand by demanding sector, and only water sources actually exposed to scarcity (groundwater and surface water), agriculture represents 5%, manufacturing 54%, the water supply industry 10%, sewerage 16%, and services 5%. These differences can be explained by three reasons: i) the high green water component in water demand for agriculture, ii) the high grey water requirements in manufacturing and sewerage (86% of the total), and iii) the relationship between the purchase and sale of intermediate inputs with embodied water, that is positive for manufacturing, sewerage and services.

These results show that mapping the sectoral structure is sensitive to the goals pursued in water management. If incentives are to be generated to reduce the direct and indirect pressures of economic activities on the quantity and quality of groundwater and surface water, an approach by demanding sector should be adopted.

The developed model also takes care of the role of resources availability in the analysis of the economic impact on water system. Specifically, a new indicator (EWEI) is proposed, which considers the requirements for blue and grey water (extended demand), and adjusts the natural supply to consider environmental, technical, and institutional restrictions (feasible supply). Previous studies, also when including the grey component of water demand, only correct the natural supply for environmental restrictions.

Once again, the case study exemplifies the differences in the water resource exploitation indicator when aspects not addressed in previous studies are considered. The indicator predominantly used in the literature (WEI+) present a value of 0.05; however, the EWEI (0.19) indicates that the Tuscany region is very close to the threshold of moderate scarcity (0.2) for an average hydrological year. The numerator of the WEI+ pressure indicator on water resources compares two quantities of water (withdrawals and discharges) of different quality. As quality is a factor affecting the potential use of water, our results confirm that a correction is necessary, as proposed by Guan and Hubacek (2008) and replicated in this study.

A significant difference is observed when disaggregating pressure indicators for groundwater and surface waters. For surface waters, the proposed indicator has a value of 0.381, significantly higher than the corresponding value of the WEI+ indicator. This means that when technical and institutional constraints are considered in determining the feasible supply, surface water resources in Tuscany show a situation of almost severe scarcity (threshold 0.4). The denominator of the standard WEI+ indicator contributes to an underestimation of pressures.

To account for variations in climate, this study estimates the EWEI for the driest and wettest hydrology within a 40-year period (1971-2010). The results show that Tuscany, in case dry hydrology, experiences moderate scarcity (0.30) on average but with huge differences between groundwater (0.07) and surface water (1.16) resources. This suggests that the region's most significant water management problems, when incorporating water quality requirements and technical and institutional constraints, concern the surface water component of the resource.

Regarding the limitations and assumptions of the proposed model, the following key elements should be highlighted. First, natural variability also applies within the same year. The annual average values of the hydrological balance components completely conceal different situations within each year in terms of natural and feasible water supply. An annual sustainable average pressure could imply critical situations during periods of the year when the natural water supply is lower.

Second, it has been assumed that agriculture extracts a certain amount of water for each euro of production directly from soil moisture. However, this assumption is only valid in years with average or above-average hydrology. In the case of dry years, agriculture extracts more from groundwater and surface waters (mainly for irrigation), increasing pressure on these resources.

Third, both the economy and the hydrological system also exhibit a geographical variability. The distribution of water intakes for irrigation clearly shows that pressures on water resources depend on the location of productive activities and the distribution of water resources in the regional territory. Critical local situations could be compatible with a sustainable global balance between extended demand and feasible water supply at the regional level.

Finally, water resource exploitation indicators, both in the standard version (WEI+) and in the extended version proposed in this study (EWEI), assume a perfect substitutability between groundwater and surface waters in the economic use. This is not necessarily the case, especially at the regional level, where there are strong geographical constraints on the movement of water resources. For this reason, even considering an average hydrology, Tuscany could be exposed to critical situations also at the regional level.

7. CONCLUSIONS

The article proposes a multisectoral and environmentally extended input-output model that represents in detail the links between the economy and the hydrological system. Water flows are mapped between economic activities and different components of the hydrological system, considering withdrawals, discharges, and the water requirements necessary to maintain the qualitative balance of the hydrological system (Extended Demand). A classification by extracting and demanding sectors is used to allocate pressures on water resources considering the both direct and indirect impacts through the purchase and the sale of intermediate inputs. To assess the water balance, an extended water exploitation indicator (EWEI) is proposed that considers a correction of the natural supply based on environmental, technical and institutional restrictions.

By empirically testing the model in the Italian region of Tuscany, our results show significant changes in the structure of sectoral pressures when considering the more comprehensive approach proposed. On average, the hydrological system of Tuscany is capable of supplying the water needed by the regional economy for medium hydrological conditions. However, the region could present moderate scarcity problems for dry years and serious scarcity problems in the case of surface waters.

The developed model can support an in-depth analysis of the water footprint of a regional economy, for example, to map pressures on water resources from specific industries to specific water bodies, and support decisions in water management both at the national and regional level.

The identified limitations suggest the direction for further refinement of the model. The interannual and intra-anual variability of the hydrological balance must be modelled. This extension of the model could allow not only to associate a measure of its potential variability with the average results, but also to simulate the impact of climate change scenarios. Furthermore, it is necessary to endogenously model the change in the composition of water sources used by agriculture, an activity that in dry years uses a greater amount of groundwater and surface water to make up for the lack of soil moisture.

Finally, the decomposition of the model at the sub-regional level could allow an evaluation of the geographical distribution of impacts on water resources and the possible existence of unsustainable local situations also within a sustainable global regional scenario.

ACKNOWLEDGEMENTS

The paper presents part of the results of the research projects «IDROREGIO – A hydro-economic model for Tuscany » funded by the Italian Ministry of Environment within the National Strategy for Sustainable Development and «RUEESNexus - A environmentally extended Rural-Urban model to study the Ecosystems-Economy-Society nexus» funded by the Ministry of University and Research (PRIN2022). Gino Sturla holds a research contract co-funded by the European Union - PON Research and Innovation 2014–2020 in accordance with Article 24, paragraph 3a), of Law No. 240 of December 30, 2010, as amended and Ministerial Decree No. 1062 of August 10, 2021.

REFERENCES

Alcamo, J., Henrich, T. Rosch, T. (2000). World Water in 2025—Global Modelling and Scenario Analysis for the World Commission on Water for the 21st Century. *Centre for Environmental System Research*. Report A0002. University of Kassel: Kassel, Germany.

Arto, I., Andreoni, V., Rueda-Cantuche, J.M. (2016). Global use of water resources: A multiregional analysis of water use, water footprint and water trade balance. *Water Resources and Economics* 15, 1-14. https://doi.org/10.1016/j.wre.2016.04.002

Braca, G., Bussettini, M., Lastoria, B., Mariani, S., Piva, F. (2021).Il Bilancio Idrologico Gis BAsed a scala Nazionale su Griglia regolare – BIGBANG: metodologia e stime. Rapporto sulla disponibilità naturale della risorsa idrica. *Istituto Superiore per la Protezione e la Ricerca Ambientale*. Rapporti 339/21, Roma.

Braca, G., Bussettini, M., Lastoria, B., Mariani, S., Piva, F. (2022). Il modello di bilancio idrologico nazionale BIGBANG: sviluppo e applicazioni operative. La disponibilità della risorsa idrica naturale in Italia dal 1951 al 2020. The BIGBANG National Water Balance Model: Development and Operational Applications. The Availability of Renewable Freshwater Resources in Italy from 1951 to 2020. *L'Acqua*, 2/2022.

Cámara, Á., Llop, M. (2020). Defining Sustainability in an Input–Output Model: An Application to Spanish Water Use. *Water.* 13(1), 1. https://doi.org/10.3390/w13010001

Casadei, S., Peppoloni, F., Pierleoni, A. (2020). A New Approach to Calculate the Water Exploitation Index (WEI^{+}). *Water.*12, (11), 3227. https://doi.org/10.3390/w12113227

CIRCABC (2012). Informal Meeting of Water and Marine Directors of the European Union. Candidate and EFTA Countries. Available online: https://circabc.europa.eu/sd/a/981c1845-a59e-4f94-8770-fc5cd0626fee/Final%20synthesis%20Heraklion%20Water%20Marine%20Directors%20clean.pdf

Deng, HM., Wang, C., Cai, WJ. Liu, Y., Zhang LX. (2020). Managing the water-energy-food nexus in China by adjusting critical final demands and supply chains: An input-output analysis. *Science of the Total Environment*, 720, 137635. https://doi.org/10.1016/j.scitotenv.2020.137635

Duarte, R., Serrano, A., Guan, D., Paavola, J. (2016). Virtual Water Flows in the EU27: A Consumption-based Approach. *Journal of Industrial Ecology* 20, 3, 547-558. https://doi.org/10.1111/jiec.12454

European Environment Agency (2020). *Use of freshwater resources in Europe*. Available online: https://www.eea.europa.eu/data-andmaps/indicators/use-of-freshwater-resources-3/assessment-4

European Environment Agency (2005). *The European Environment—State and Outlook 2005*. European Environmental Agency: Copenaghen, Denmark. https:// /view https://www.eea.europa.eu/publications/state_of_environment_report_2005_1/SOER2005_all.pdf/at_download/file

Faergemann, H. (2012). Update on Water Scarcity and Droughts indicator development. In *EC Expert Group on Water Scarcity & Droughts*. European Environment Agency. Brussels, Belgium; pp. 1–23.

Feng, K., Hubacek, K., Pfister, S., Yu, Y., Sun, L. (2014). Virtual Scarce Water in China. *Environmental Science and Technol*ogy, 48, 14, 7704–7713. https://doi.org/10.1021/es500502q

Garcia-Hernandez, J., Brouwer, R. (2021). A multiregional input–output optimization model to assess impacts of water supply disruptions under climate change on the Great Lakes economy. *Economic Systems Research*. 2021, 33, (4), 509–535. https://doi.org/10.1080/09535314.2020.1805414

GSE (2022). *Elenco impianti elettrici*. Gestore Servizi Energetici, Italia. www.gse.it

Guan, D., Hubacek, K. (2008). A new and integrated hydro-economic accounting and analytical framework for water resources: a case study of North China. *Journal of Environmental Management*, 88: 1300-1313.

Hoekstra, A.Y., Chapagain, A.K., Mekonnen, M.M., Aldaya, M.M. (2011). *The Water Footprint Assessment Manual: Setting the Global Standard*. 1st ed.; Earthscan: London, UK. ISBN 978-1-84977-552-6.

ISTAT (2019a). Struttura e caratteristiche delle unità economiche del settore agricolo. Anno 2017. *Statis-*

tiche Report, 2 dicembre 2019. https://www.istat.it/it/files//2019/12/Struttura-unit%C3%A0-economiche-settore-agricolo.pdf

ISTAT (2019b). *Utilizzo e qualità della risorsa idrica in Italia*. Roma, Istituto Nazionale di Statistica. https://www.istat.it/it/archivio/234904

Kenny F., Barber N., Hutson S., Linsey K., Lovelace J., Maupin M. (2009). Estimated Use of Water in the United States in 2005. *US Geological Survey Circular.* Vol 1344 (Reston, VA: USGS).

Lee, LC., Wang, Y., Zuo, J. 2021. The nexus of water-energy-food in China's tourism industry. *Resources, Conservation & Recycling*, 164, 105157. https://doi.org/10.1016/j.resconrec.2020.105157

Lenzen, M.,Moran, D., Bhaduri, A., Kanemoto, K., Bekchanov, M., Geschke, A., Foran, B. (2013). International trade of scarce water. *Ecological Economics*. 94, 78–85. https://doi.org/10.1016/j.ecolecon.2013.06.018

Macknick, J., Newmark, R., Heath, G., Hallett, K.C. (2012). Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature. *Environmental Resource Letters.* 7, 045802 (10 pp.).

Meng, Xu, Chunhui Li, Xuan Wang, Yanpeng Cai, Wencong Yue (2017). Optimal water utilization and allocation in industrial sectors based on water Footprint accounting in Dalian City, China. *Journal of Cleaner Production*. Volume 176, 1283-1291. https://doi.org/10.1016/j.jclepro.2017.11.203

Miller, T., and Blair, P. (2009). *Input-Output Analysis: Foundations and Extensions*. Cambridge University Press. Cambridge (UK). 2nd Edition.

OECD. (2015). *Water: Freshwater abstractions (Edition 2015)*. OECD Environment Statistics (database). https://doi.org/10.1787/f9f5fcd1-en

Pfister, S., Koehler, A. and Hellweg, S. (2009). Assessing the Environmental Impacts of Freshwater Consumption in LCA. *Environmental Science and Technology* 43, 11, 4098–4104. https://doi.org/10.1021/es802423e

Raskin, P., Gleick, P.H., Kirshen, P., Pontius, R.G., Strzepek, K. (1997). *Comprehensive Assessment of the Freshwater Resources of the World*. Document prepared for UN Commission for Sustainable Development 5th Session. Stockholm Environmental Institute: Stockholm, Sweden.

Ridoutt, B., Hadjikakou, M., Nolan, M., Bryan, B.A. (2018). *From Water-Use to Water-Scarcity Footprinting in Environmentally Extended Input–Output Analysis*. *Environonmental Science and Technology* 52, 6761–6770. https://doi.org/10.1021/acs.est.8b00416

Rossi, G., Benedini, M. (2020). *Water resources of Italy. Protection use and control*. Springer. First Edition. https://doi.org/10.1007/978-3-030-36460-1

Rossi, G., Caporali, E. (2010). Regional Analysis of low flow in Tuscany (Italy). *Global Change: Facing Risk and Threats to Water Resources*. IAHS Publ. 340.

Salvadori, L., Ferrari, S., Pusceddu, A.. Carucci, A. (2020). Implementation of the EU ecological flow policy in Italy with a focus on Sardinia. *Advances in Oceanography and Limnology, vol.* 11(1), 23–34.

Settore Idrologico e Geologico Regionale (SIR). (2021). *Strati GIS*. https://www.sir.toscana.it/strati-gis

Sturla, G., Ciulla, L., Rocchi, B. (2023). Natural and social scarcity in water footprint. A multiregional input-output analysis for Italy. *Ecological Indicators*, 147 (109981): https://doi.org/10.1016/j.ecolind.2023.109981.

Sturla, G., Ciulla, L., Rocchi, B. (2024). Estimating the global production and consumption-based water footprint of a regional economy. *Sustainable Production and Consumption*, 44: 208-2020. https://doi.org/10.1016/j.spc.2023.11.023.

Velazquez, E. (2006). An input–output model of water consumption: Analysing intersectoral water relationships in Andalusia. *Ecological Economics*. 56(2), 226–240. https://doi.org/10.1016/j.ecolecon.2004.09.026

Venturi, C., Campo, L., Caparrini, F., Castelli, F. (2014). The assessment of the water consumption at regional scale: An application in Tuscany, Central Italy. *European Water*. 46/46, 3–23.

Wang, D., Hubacek, K., Shan, Y., Gerbens-Leenes, W., Liu, J. (2021). A Review of water stress and Water Footprint Accounting". *Water*. 13, 201, 1–15.

Weber, C., Peters, G. Hubacek, K. (2008). The contribution of Chinese exports to climate change. *Energy Policy*. 36 (2008), 3572–3577.

White, DJ., Hubacek, K., Feng, K., Sun, L., Meng, B. (2018). The Water-Energy-Food Nexus in East Asia: A tele-connected value chain analysis using inter-regional input-output analysis. *Applied Energy*, 210, 550–567. https://doi.org/10.1016/j.apenergy.2017.05.159

Xiao, Z., Yao, M., Tang, X., Sun, L. (2019). Identifying critical supply chains: An input-output analysis for Food-Energy-Water Nexus in China. *Ecological Modelling*, 392, 31–37. https://doi.org/10.1016/j.ecolmodel.2018.11.006

Xie, Y. (1996). Environment and Water Quality Model. *China Science and Technology Press*, Beijing, China.

Finito di stampare da
Logo s.r.l. – Borgoricco (PD) – Italia

Bio-based and Applied Economics Focus and Scope

The journal *Bio-based and Applied Economics* (*BAE*) provides a forum for presentation and discussion of applied research in the field of bio-based sectors and related policies, informing evidence-based decision-making and policy-making. It intends to provide a scholarly source of theoretical and applied studies while remaining widely accessible for non-researchers.

BAE seeks applied contributions on the economics of bio-based industries, such as agriculture, forestry, fishery and food, dealing with any related disciplines, such as resource and environmental economics, consumer studies, regional economics, innovation and development economics. Beside well-established fields of research related to these sectors, *BAE* aims in particular to explore cross-sectoral, recent and emerging themes characterizing the integrated management of biological resources, bio-based industries and sustainable development of rural areas. A special attention is also paid to the linkages between local and international dimensions. *BAE*'s objectives are:

- to stimulate cross-fertilization between the above mentioned research fields;
- to synthesize and integrate lessons learned from current strands of literature in economics;
- to provide a forum for well-established scholars as well as promising young researchers;
- to increase the knowledge about assessment, design and evaluation of public policies;
- to promote the debate on issues relating to the economics profession and its consultancy activities;
- to discuss future research pathways on the above issues.

***BAE* publishes high quality research and review papers, after a timely and rigorous double blind peer review process. *BAE* also publishes book reviews.**

BAE
Bio-based and Applied Economics

Full Research Articles