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Abstract

The EU's Common Agricultural Policy (CAP) has been broadened over recent decades in response to evolving challenges faced by the EU and its farmers. It now claims to support not only food security and farmers' incomes, but also transitioning to a green economy, conservation of biodiversity and climate action. We have evaluated to what extent four main types of CAP payment instruments form a cohesive and effective package for achieving multiple policy goals in mixed forestry-farming regions (skogsbyggder); regions that are crucial for the provisioning of public goods in Sweden. We find that these payments collectively are vital for achieving policy goals for agriculture in these regions, but the complex mix of instruments hides the potential for achieving better trade-offs among policy goals. Instead of comprising a coherent response to policy goals, the current mix of instruments represents a patchwork of responses to potentially conflicting goals. Our study indicates that the CAP can be made more effective in mixed forestry-farming farming regions through better coordination of its main payment instruments given its multiple goals.

JEL Codes: Q18; Q24; Q57

Keywords: biodiversity; ecological-economic modelling; methane; sustainable agriculture; grassland; multifunctional

1 Introduction

The perpetuation of low-intensity, extensive farming systems is crucial for the conservation of biodiversity and cultural landscapes in the European Union (EU). Examples of such High Nature Value (HNV) farming, which is conducted on around 25% of the EU's agricultural area (Paracchini*, et al.*, 2008), include: grazing on semi-natural pastures (Eriksson, 2021), mountain agriculture (MacDonald*, et al.*, 2000) and uplands farming (O'Rourke*, et al.*, 2016). Typically, these systems are reliant on an assortment of Common Agricultural Policy (CAP) payment instruments for their perpetuation; over 100 individual schemes are funded across the EU from the CAP budget of around €60 billion annually (Scown*, et al.*, 2020). HNV systems are vulnerable to discontinuation because they would be either unprofitable, or less profitable than intensive farming systems and farming in more productive regions without CAP payments. Furthermore, these regions are particularly susceptible to structural change in the form of declining numbers of farms and specialization, which is perceived as a problem by policymakers due to the potential loss of associated public goods. Overall, around 30% of the EU's agricultural area has a moderate to high risk of abandonment by 2030, of which areas of HNV farmland are particularly at risk (Schuh*, et al.*, 2020).

A continuing challenge for European agriculture is remaining competitive on global markets, while simultaneously providing the public goods associated with the European multifunctional model of agriculture (Blandford and Hill, 2005). In this respect structural change—what, where and how we produce our food (Goddard*, et al.*, 1993)—is necessary for keeping pace with the global competition, but on the same token efficient solutions need to be identified for the provisioning of public goods (Balmann*, et al.*, 2006). This challenge requires better understanding of how the current policy-instrument mix influences structural change, and how the resultant path of structural change influences the supply of public goods from agriculture (Gouriveau*, et al.*, 2019).

Despite the EU being a major food exporter, globally competitive agriculture tends to be found in intensively farmed regions with attendant high application rates of chemical pesticides and mineral fertilizers, or extremely high livestock densities, thereby causing widespread environmental damage through pollution of water, degradation of biodiversity and emissions of green-house gases (Stoate*, et al.*, 2009). For these reasons we focus in this paper on HNV farming systems, specifically mixed forestry-farming regions, for their provisioning of public goods and need for collective financing, since efficient levels of public goods are unlikely to be financed through market forces, resulting in market failure.

According to Daugbjerg and Swinbank (2016), the growth in CAP instruments in recent decades has occurred because new CAP objectives have been layered on the old—those relating to agricultural production, competitiveness, farm incomes, etc.—rather than replacing them with the new—those relating to climate-change action, environmental care, preservation of landscapes and biodiversity, as well as vibrant rural areas (EC, 2022). A fundamental question for policy analysis is, therefore, whether the resultant mix of instruments and their budgetary magnitudes is a coherent and effective response to the CAP's current objectives, or a patchwork of instruments not forming a coherent whole; and for this reason undermining its objectives (e.g., Matthews, 2022).

Our overarching aim is to evaluate to what extent four main types of CAP payment instruments form a cohesive response for achieving policy goals in mixed forestry-farming regions. Specifically, we evaluate their long-term impacts on structural change and the environment in a representative mixed forestry-farming region, Jönköping County in southern Sweden. The four instrument types we consider are i) Decoupled payments in the form of the Basic Payment Scheme (**BPS**)[1], ii) Voluntary Coupled Support to livestock (**VCS**)[2], iii) Compensation payments in Areas with Natural Constraints (**ANC**) and iv) an Agri-Environment-Climate Measure payment for preserving biodiversity (**AECM**), which together account for the majority of CAP spending (Scown*, et al.*, 2020).

To do this we combine a dynamic and spatial agent-based economic model of agricultural structural change (AgriPoliS) with environmental modelling to simulate the long-term impacts of each instrument on regional agricultural structure, food production and the environment. We apply the analysis to Jönköping County in Sweden, a county with a large area of semi-natural pastures (25% of the agricultural area) that are crucial for conservation of biodiversity and the cultural landscape in Sweden (Nilsson*, et al.*, 2013).

Few studies connect agricultural policy, structural change, and the environment. Nevertheless, it has long been recognised that structural change in agriculture is a major driver of the negative environmental impacts of modern agriculture, particularly through intensification of production with mineral fertilizers and pesticides (Knickel, 1990, Lu, 1985). Less attention though has been paid to the appropriate choice of policy instruments for achieving multiple policy goals in HNV farming regions. Eadie (1985) claimed almost four decades ago "subsidies will have to be further increased, or the agricultural population and its contribution to the upland economy will both continue to decline." At the time, subsidies meant production subsidies, thereby ignoring the potential for other types of instruments such as AECMs to maintain environmental values in HNV regions, an oversight that is still prevalent today. The "belief that maintenance of the status quo, with policies strongly [coupled] to agricultural production, is necessary to conserve the multifunctionality[3] of agriculture" can be traced back to discussions at the WTO and OECD in the mid-1980s when the first attempts to reform agricultural policies were being made to reduce global production surpluses (Cahill, 2001). Indeed, links between production and public goods exist (jointness in production), but these are complex, can vary in their strength, and come in the form of both desirable and undesirable effects (Potter and Burney, 2002). This complexity makes theoretical resolution of the appropriate policy response difficult.

Our paper contributes to the literature by linking choices of agricultural policy instruments to structural change and attendant environmental impacts in a comparative analysis, which has not been done before in such a manner. Generally, the literature focuses on only one or two aspects of the policy effect chain, making it difficult to conclude about the overall effectiveness of current policy instruments and their potential interactions.

2 Modelling structural change and environmental impacts

To achieve our aim, we need a method sufficiently flexible to capture specific features of the agricultural landscape in a region that affect farm profitability and the provision of public goods. For example, the spatial distribution and size of agricultural land parcels affect costs of field operations, due to economies of scale associated with larger fields, but also the availability of habitat for wild organisms (Clough*, et al.*, 2020). Regional characteristics, such as soil fertility and climate, influence

[1] From 2023 is called Basic Income Support for sustainability (BIS).
[2] From 2023 is called Coupled Income Support (CIS)
[3] Multifunctionality or agricultures' non-commodity outputs refers to the provisioning of public goods such as conservation of biodiversity and preservation of cultural landscapes that have evolved with European agriculture over the eons, and for which markets do not exist or function poorly, resulting in market failure.

the profitability of growing different crops and, consequently, the likelihood of specific farm types and associated public goods emerging in the region (Boke Olén*, et al.*, 2021, Karlsson*, et al.*, 2022). These characteristics of farm structures offer, on the other hand, potential to manage trade-offs among the multiple objectives of the CAP depending on the amount of land allocated to particular types of farming or farming technologies, both of which can be influenced by policy.

Balmann (1997) introduced a model-based approach for analyzing agricultural structural change, aiming to capture complex interactions such as competition for land through simulations. Expanding on this work, Happe (2004) developed AgriPoliS, an empirical, spatial, and dynamic agent-based model for assessing policy impacts on regional agricultural structure. Subsequent studies by Happe*, et al.* (2006), (2008) applied the AgriPoliS model, revealing the existence of path dependencies. This suggests that policy instruments may have varying effects across the EU depending on unique regional histories, such as those characterized by HNV farming.

AgriPoliS has also been shown to be suited for assessing the environmental impacts of agricultural policy choices due to its ability to capture individual farm-agent decisions and local conditions. Studies by Brady*, et al.* (2009) and (2012) demonstrate that decoupled payments introduced in 2005 slow structural change generally, and have important consequences for biodiversity and landscapes in HNV regions. Similarly, Uthes*, et al.* (2011) found that regional characteristics and biophysical conditions significantly influence the impacts of agricultural policy reform, leading to diverse development trends and environmental impacts. The interplay between structural changes, nitrogen losses, and environmental regulation was also demonstrated by Happe*, et al.* (2011). Recent applications of the AgriPoliS model assessed the effectiveness of the 2015 CAP reform, showing the limitations of associating income payments with general environmental conditions for improving environmental performance (Hristov*, et al.*, 2020, Sahrbacher*, et al.*, 2017).

In summary, AgriPoliS after two decades of development serves today as a flexible tool for evaluating the relationships among different policy instruments, structural change, and their impacts on multiple policy goals.

3 Study region and modelling of policy instruments

Jönköping County is typical of HNV farming in Sweden (Figure 1) in that mixed agricultural and silvicultural enterprises are dominant due to prevailing soil and topographic conditions. Roughly 73 per cent of Sweden's productive forest or 17 million ha is owned in combination with agricultural land, compared to the total agricultural area of just over 3 million ha or 7 % of the country's land area (SJV, 2015). Open agricultural land and particularly semi-natural pastures are therefore a relatively scarce land use in Sweden, but crucial for the conservation of biodiversity (Eriksson, 2021).

Figure 1. Showing location of Jönköping County in Sweden and the spatial distribution of arable land, semi-natural pastures and forest. Source: Swedish National Land Cover Database (Swedish EPA, 2024).

Topographic characteristics and the distance to farm centres explain most of the ongoing loss of semi-natural pastures in Sweden; from a historical high of almost 3 million ha to the current area of around 450 thousand ha (Aune*, et al.*, 2018). In general, relatively small and isolated pastures are most likely to be abandoned (afforested), because these are more costly to manage than a large pasture lying close to livestock stables. Subsequently, it is continually stated by sector representatives that profitable agricultural production is a prerequisite for conserving biodiversity in the Swedish agricultural landscape (e.g., SJV, 2019). However, this is hardly a sufficient characterization of the problem. Rather it needs to be profitable for farmers to preserve biodiversity and not simply to hold cattle. Alternatively, payments for preserving pastures *per se* indirectly provide incentives to invest in stables and to transport livestock longer distances when it is not feasible to build stables in proximity to pastures. This pattern is strongly evident in the current distribution of stables, which are very often located at considerable distance from pastures (Larsson*, et al.*, 2020).

3.1 Total payments for selected policy instruments

Agriculture is supported by a mix of payment instruments in Jönköping County, like in most other HNV farming regions. Together, the four main types of CAP payments selected for analysis, account for 93 % of CAP payments in the study region (83 % in the EU) and average, in total, 4 646 SEK per ha agricultural land (Table 1).

Table 1. Total CAP payments to farmers for the evaluated instruments in the study region and the EU for comparison

		Jönköping 2016 (1)		**EU 2016 (2)**	
Instrument name	**ID**	*SEK (millions)*	*%*	*EURO (billions)*	*%*
Basic Payment Scheme	BPS	239.5	45	40.4	66
Voluntary Coupled Support	VCS	71.8	14	4.2	7
Compensation Payments	ANC	126.6	24	2.5	4
Agri-Environment-Climate Measures	AECM	53.5	10	3.5	6
Other instruments		35.3	7	10.3	17
Total CAP support		**526.7**	100	**60.9**	100

Sources: (1) According to SCB (2018). Note that the proportional distribution of payments has remained largely unchanged over the evaluated CAP programme period ending 2022. (2) According to (Pe'er, et al., 2020).

Given that the mathematical structure of AgriPoliS is fully specified in Kellermann*, et al.* (2008) we show here how the different types of policy instruments chosen for analysis are modelled and assumed to impact individual farm-agents' optimal choices.

3.2 Modelling farmers' behaviour

We begin by presenting a mathematical representation of the farm-agents' fundamental optimization problem that they solve repeatedly to plan their activities at the start of each simulation period (year) given their resource endowments, and potential investment and land acquisition possibilities. Their planning problem is formulated as a linear, Mixed Integer Programme (MIP) following standard practice in agricultural economics (e.g., Hazell and Norton, 1986).

Farm-agents are assumed to be myopic and hence are unaware of how prices or policy payments will change more than one year into the future. Rather, they follow adaptive expectations based on previous years' prices. Individual farm-agents are also price takers such that the prices they face are given at the start of each simulation period. The individual farm-agents' family-income maximization problem is defined as follows:

$$\begin{aligned} Max\ \pi(Y,X,A,Z) = & \sum_{j}^{J}\left[\left(p_j + s_j - c_j\right)Y_j\left(N_{j,m}\right) + \left(\mathrm{bps}_c + \mathrm{vcs}_l + \mathrm{anc}_e + \mathrm{aecm}_d\right)\right]X_j - \sum_{j}^{J}\sum_{m}^{M} w_m N_{j,m} + \\ & + \mathrm{ir}X_{\mathrm{cash}} + \mathrm{wo}X_{\text{off-farm}} - \sum_{n}^{N}\mathrm{re}_n A_{\mathrm{rented},n} - \mathrm{ip}X_{\mathrm{loans}} - \mathrm{wh}X_{\mathrm{hired}} - \sum_{l}^{L}\sum_{k}^{K}\left[\left(\mathrm{mc}_{l,k} + \mathrm{de}_{l,k}\right)\bar{Z}_{l,k} - \mathrm{tac}_{l,k} Z_{l,k} I_{l,k}\right] \\ & - \mathrm{tc}D_{\mathrm{field}_j} + BENEFIT\_FARM\_LIFE \end{aligned} \quad (1.1)$$

subject to

$$\sum_{j}^{J} r_{j,k} X_j \leq \bar{R}_k, \qquad \forall\ \mathrm{k} \subseteq K \quad (1.2)$$

$$\sum_{c}^{LAND\_USES} X_c \leq \bar{A}_n + A_n^{\mathrm{rented}}, \quad \forall n \in \mathrm{LAND\_USES} \quad (1.3)$$

$$\sum_{j \in I}^{J} X_j \leq \sum_{k}^{K} \left(\bar{Z}_{i,k} + Z_{i,k} \right), \qquad \forall\, i \in \text{ INVESTMENT\_TYPES} \tag{1.4}$$

$$\sum_{e}^{\text{ANC\_LAND\_USES}} r_{\text{e,anc}} X_{\text{e,anc}} \leq 0, \qquad \forall\, anc \subseteq K \tag{1.5}$$

$$\sum_{f}^{\text{AECM\_LAND\_USES}} r_{f,\text{ aecm}} X_{f,\text{ aecm}} \leq 0, \qquad \forall\, aecm\,. \tag{1.6}$$

Each farm-agent (not indexed for clarity) is characterized by a set of resource endowments: their areas of owned agricultural land $\bar{A}_n$ (ha) of type *n*, family labour $\bar{L}$ (hrs) available for work on or off the farm, financial capital $\bar{C}$ (SEK), and existing machinery and stables $\bar{Z}_{i,k}$ (ha or number of animal places) of capacity *k* that is necessary for conducting activities of type *i,* e.g., crop production requires machinery and milk production requires a stable to house dairy cows. Investments in larger capacities of machinery and stables increase productivity by lowering management costs (particularly labour needs) per ha land or stable place. New investments are modelled as an integer programming problem as stables and machinery can only be acquired in discrete capacities (e.g., 30, 60, 120,… places), which is represented by the integer variable $I_{i,k}$ = (1 or 0). Investments in additional capacity $Z_{i,k}$ can be made at an annualized total acquisition cost of $tac_{i,k}$. Existing investments require maintenance at rate $mc_{i,k}$ and are depreciated at rate $de_{i,k}$. Existing investments, however, are treated as sunk costs for planning production in subsequent simulation periods.

Farm-agents in AgriPoliS are assumed to maximize their total family income (π) by choosing optimal levels of their $j \in$ J possible agricultural production activities denoted by the decision variables X_j, which are measured as hectares of different crops, numbers of different livestock, hours of own or hired labour, etc. For some activities it is necessary to model the yield associated with the activity endogenously, since yields of arable crops can be influenced by soil quality and fertilizer input. Hence the yield of crop $c \in$ LAND_USES $\subseteq$ J is denoted $Y_j(N_{j,k})$, implying that yield is a function of inputs $N_{j,k}$ (kg/ha) where *k* denotes a particular input such as nitrogen fertilizer. Yield is measured in dry weight for crops as kg/ha or kg/animal whichever the case might be. Further, market activities exist for saleable crops, since crops such as barley can be fed to farmers' own livestock or sold on the market.

Farm-agents face a range of market related revenues and costs. These are the expected prices for outputs (p_j), yield dependent costs (w_m) and area/place dependent input costs (c_j). Family income can also be augmented with off-farm revenues, receiving interest rate *ir* (%) for liquid capital not used on the farm, X_{cash} *(SEK*), and wage *wo* (SEK/hr) for off-farm work, $X_{off\text{-}farm}$ (hrs). There are also joint costs associated with running the farm: rent paid, re_n *(SEK/ha),* per ha of rented land of type *n,* $A_{rented,n}$ *(ha)*; interest paid at rate *ip* on loans, X_{loans} (SEK), to finance investments, and wage rate *wh* (SEK/hr) paid to hired labour, X_{hired} (hrs).

To account for farmers' non-pecuniary benefits of the farming life (Key and Roberts, 2009), we include a benefit, BENEFIT_FARM_LIFE, valued at 75 000 SEK p.a. in the income calculation for active farming independent of farm size. Such a payment is required to explain why small farms continue in reality with farming, despite inadequate profitability according to AgriPoliS without this payment.

Beyond the farm-agents' fundamental optimization problem, Eqs. (1.1)–(1.6), AgriPoliS has sub-models to handle dynamics (e.g., monitor how farm-agents' stocks of capital change during each simulation period), the spatial distribution of farm centres and agricultural land, interactions among farm-agents on the endogenous land market and clearing of any regional markets (e.g., for calves, piglets, stable manure, quotas, etc.). Farm-agents solve this problem repeatedly to derive maximum bids for renting land on the rental market, based on the shadow price of obtaining additional blocks of agricultural land. This process is managed by the auctioneer agent in AgriPoliS. Similarly, regional markets (e.g., calves) are managed by market agents to maintain balance between demand and supply or environmental regulations (e.g., stable manure) in the region.

3.3 Strategic decisions

Farm-agents will continue with farming or invest in the coming year only if the profit they expect to make at the end of the coming year is expected to be greater than the opportunity costs of own factors (family labour, equity capital and land). Family labour is valued at the off-farm wage level (*wo*), equity capital at the interest rate for long-term loans (*ir*), and owned land at the average regional rental price (i.e., the area-weighted average rental price of re_n for the region). A farm will close down if a) the expected income for the coming year fails to cover variable costs and opportunity costs for their own factors, b) the farm is insolvent or c) because a successor does not exist when the farm agent reaches the assumed retirement age of 65. Once a farm closes down, its land is released to the endogenous rental market. Since agricultural land is strictly limited, farms can only expand if others quit or reduce their area of rented land.

3.4 Theoretical impacts of modelled CAP instruments

Next, we describe how we model the policy framework and the potential impacts of each instrument on farm-agent behaviour. First, note that potential price support is captured by the parameter s_j (SEK/kg). Otherwise, the evaluated policy instruments are paid per ha of an eligible land use or livestock category subject to specific management requirements, which are modelled via relevant constraints on the farm-agents' optimization problem.

3.4.1 Basic Payment Scheme (BPS)

The Basic Payment Scheme (BPS) is a decoupled payment, meaning it does not require production for collection. Instead, it is contingent on maintaining farmland in "Good Agricultural and Environmental Condition" (GAEC) and complying with various conditions related to the environment and animal welfare. The minimum land-use requirement for the BPS payment is grass-sown fallow (also known as set-aside in CAP terminology), while cropping activities automatically fulfil the requirement. It is paid at a uniform rate of bps_c per ha eligible land use $c \in$ LAND_USES $\subseteq$ J.

The BPS affects the extensive margin, making it more profitable to farm or maintain land as fallow instead of abandoning it. Consequently, it can indirectly increase production if using land for production is the least costly way to fulfil the GAEC obligation. The BPS also influences strategic decisions. Firstly, it raises the opportunity cost of closing a farm since it contributes to covering the opportunity costs of own labour and capital. Secondly, it can increase equity capital over time, reducing the risk of insolvency and enabling financing for investments. As a result, the BPS slows structural change by reducing the rate at which farms exit agriculture (Brady*, et al.*, 2009). However, if the BPS has no impact on land use because all land is profitable for production, it tends to capitalize into land rental prices over time, undermining its potential to support incomes (Varacca*, et al.*, 2021).

3.4.2 Voluntary Coupled Support (VCS)

The majority of Voluntary Coupled Support (VCS) payments in the EU go to livestock sectors, primarily cattle and sheep, and exclusively to cattle in our study region. We model VCS as a payment per head of eligible livestock vcs_l where $l \in$ LIVESTOCK $\subseteq$ J, is a subset of livestock activities such as suckler cows, dairy cows, etc.

The VCS is only payable to a small subset of activities, which increases the profitability of these activities relative to all other activities. Consequently, we can expect higher levels of the supported activities than would otherwise be the case, e.g., more cattle and less sheep, or more meat and less grain for food. Since there are no additional management requirements it is a pure production subsidy and will raise farm profitability, ceteris paribus. The primary impact is to increase production of the supported activity (Jansson*, et al.*, 2021). This in turn increases emissions associated with production such as nutrients and GHGs (ibid.), but could also contribute to conservation of pastures if more ruminants are kept and used for grazing.

3.4.3 Areas of Natural Constraints Payments (ANC)

ANC payments are a form of coupled payment, as they are linked to productive agricultural activity in particular areas. These are Areas with Natural Constraints, such as those having relatively poor soil quality and climate for agriculture. In this sense they are intended to compensate farmers for the higher production costs associated with these areas, such as in our study region and HNV farming elsewhere. These payments are more complex compared to the BPS and VCS schemes as they are contingent on farmers fulfilling more specific criterion, for example varying with livestock density and farm size. Although they are paid per ha agricultural land, associating them with a density requirement implies they indirectly subsidize livestock. Consequently, ANC payments are paid at rate anc_e per ha eligible ANC land use, $e \in$ ANC_LAND_USES $\subseteq$ J. Further, the payments are subject to a set of management and eligibility constraints represented by Eq. (1.5).

Due to the complexity of the ANC payments, their effects are less straightforward to predict, particularly the potential for indirect impacts. Similar to the VCS they are likely to increase emissions because they increase production, but may also contribute to the conservation of biodiversity through increased use of pastures.

3.4.4 Agri-Environment-Climate Measures (AECM)

Agri-Environment-Climate Measures are payment schemes that compensate farmers for the additional costs of taking actions to improve environmental quality, conserve biodiversity or reduce GHG emissions. Typically, these are tied to the implementation of particular management practices such as the creation of grass buffer zones to reduce runoff, flower strips to provide habitat for pollinators or grazing of grasslands to conserve biodiversity. These are paid at rate $aecm_d$ per ha eligible land use, where $d \in$ LAND_USES $\subseteq$ J. As with ANC payments, these are subject to a set of management requirements represented by Eq. (1.6). For example, in our study region the majority of AECM payments are directed towards the maintenance of semi-natural pastures, which is modelled as a particular grazing intensity.

If sufficiently high, these payments will increase the area of supported land uses without adversely affecting farm profitability. While the environmental effect is expected to be positive on the targeted variable, e.g., biodiversity associated with the grazing of pastures, negative impacts might also occur, such as increased methane emissions associated with higher numbers of ruminants.

3.4.5 Summary

The four main CAP instruments have similarities regarding their effects on farm-agent behaviour, because they are all based on payments per unit of agricultural activity. This helps to explain why total CAP payments to “a farm” are often discussed in reform debates as they indicate reliance on support. But, when considering long-term structural and environmental impacts they are likely to differ considerably, according to the analysis above.

In practice, the impact of each payment on optimal activity levels, structural change, and the environment depends on eligible activities and associated management obligations, which affect collection costs. Stricter obligations lead to higher costs. Changes in relative profitability in turn influence investments, and farm expansion or closure decisions, shaping the regional structure as an emergent result of individual farmers' behaviour.

All four instruments potentially interact, thereby strengthening the influence on structural change and subsequently the environment. Predicting the impacts of the BPS, VCS and ANC payments on structural change and the environment is not straightforward due to regional variations in agricultural productivity and the landscape. However, they all provide incentives for farms to remain in production. AECM are also likely to influence structural change, but promoting a farm structure that generates higher overall levels of environmental public goods.

3.5 Model calibration and validation

The regional model for Jönköping was initially calibrated to the structure of agriculture prevailing in the study region in 2016 according to relevant statistics. It was then dynamically calibrated 'to structural trends over the period 2017-21 using statistics from those years. This ensures that the model accurately reflects the observed structural changes in the region over this period. Subsequently, the model is run until 2030 to simulate the reference scenario (REF) that extends the policy framework from 2015-22 to 2030.

4 Evaluated policy scenarios

The effects of the selected policy instrument (**BPS**, **VCS**, **ANC** and **AECM**) were simulated by creating a counterfactual scenario that reduced payments of each type over a four-year phasing-in period (2020-23). To make the evaluation of instruments as comparable as possible, as well as substantial, we reduced each payment type by the same absolute amount, which is the level of the AECM payments because it has the lowest total payments for the region (Table 2). Removing the payments completely or reducing them by a certain proportion, would introduce a volume bias, since total payments of each type vary substantially. Furthermore, phasing in the reductions helps avoid short-term liquidity problems for farm-agents and hence unnecessary farm closures. Additionally, we ran a scenario where all four instruments were reduced simultaneously (**CAP**) by the same amounts to understand the combined impacts. Given potential interactions among the instruments, we anticipate that this scenario will have stronger effects on structural change and the environment compared to any single instrument. We evaluated each policy scenario by comparing relevant structural and environmental indicators to the reference scenario in 2030.

Table 2. Evaluated policy scenarios, base-line payment levels and modelled reductions in payments

ID	**Scenario Name**	**Description of how scenario was implemented**	**Total Modelled Payments 2016#** *(SEK mil.)*	**Reduction in payment type by scenario*** *(%)*
SC0	REF	Reference scenario: continuation of CAP 2015-2020	**489.6**	none
SC1	BPS	Reduce Basic Payment Scheme	240.0	22
SC2	VCS	Reduce Voluntary Coupled Support	70.8	73
SC3	ANC	Reduce Payments to Areas with Natural Constraints	127.1	41
SC4	AECM	Reduce Environmental Payments to semi-natural pastures	51.6	100
SC5	CAP	Reduce all four payment types simultaneously according to SC1–4 assumptions		**42**

*Notes: # Total payments by instrument type and for all four instrument types in Baseline year, 2016, according to our calibrated model, which vary marginally from the actual payment levels (Table 1) due to an imperfect but adequate representation of agricultural structure in the region. * Total payments of the applicable payment type in SC1-4 are reduced by 51.6 SEK million (i.e., the level of total AECM payments, which has the lowest total payments).*

5 Impact indicators

Modelling the impacts of the different policy instruments on farm structure and incomes, as well as on broader societal impacts (biodiversity, climate gas emissions and food production) will allow us to evaluate trade-offs among main CAP goals.

5.1 Agricultural structure

Impacts on regional farm structure are evaluated in terms of the number and average size of farms, average farm incomes, and average rental prices for arable land and semi-natural pastures. Land use is valuated in terms of changes in the area of different agricultural land-use activities: annual crops, grasses, fallow, etc., while livestock structure is evaluated in terms of changes in the holdings of different types of livestock (beef cattle, dairy cows, etc.).

5.2 Societal impacts

We have chosen to evaluate the effects of the different instruments types on three main societal impacts from HNV farming beyond agriculture per se: conservation of biodiversity, emissions of climate warming gases and contribution to national food security.

5.2.1 Biodiversity: area of semi-natural pastures

As discussed above, HNV farming regions are, per definition, important for the conservation of biodiversity and associated ecosystem services in the EU generally, and in our study region particularly, thanks to the large area of semi-natural pastures. Accordingly, we use the area of semi-natural pastures as an indicator for conservation of biodiversity.

5.2.2 Climate warming: enteric methane emissions

Since HNV farmland regions generally, and our study region in particular, are orientated towards grassland fodder production to support ruminants, climate-warming methane emissions are a negative environmental impact associated with HNV farming. In particular, enteric methane gas emissions (i.e., those from the digestion process of ruminant livestock) account for around 50 % of agriculture's emissions of climate warming gases in Sweden and the EU (European Environment

Agency, 2023). We focus therefore on enteric methane because there is a potential trade-off between reducing these emissions and preserving semi-natural pastures. In contrast GHG emissions from manure management (including methane and nitrous oxide), depend heavily on management systems, while CO_2 emissions from land use changes or N_2O emissions from fertilizers, are not directly linked to livestock numbers.

Annualised enteric methane emission rates for livestock are modelled in AgriPoliS based on the method used by the Swedish EPA (2023) for their GHG emission reporting. All methane emissions are subsequently expressed as carbon dioxide equivalents (CO_2e), by multiplying kg methane emitted by the conversion factor of 28 (Masson-Delmotte*, et al.*, 2021, Table 7.15).

5.2.3 National food security

Food production is obviously the primary function of agriculture and a certain level of domestic food production is essential for a country's food security. To evaluate the impacts of the different policy instruments on food production we convert outputs from crop and livestock production to their equivalent food potential measured in calories (kcal), which makes it possible to aggregate across different agricultural products, in this case final food products (bread grain, milk, meat, etc.).

6 Results

6.1 Regional agricultural structure

We present the impacts on agricultural structure in terms of how each instrument influences farm structure, land use and livestock holdings.

6.1.1 Farms and farmers' incomes

Each of the instruments influence structural change in the same directions, maintaining a greater number of farms, smaller farm size and higher average farm profit than would otherwise be the case (Figure 2). The BPS and AECM have stronger impacts on preserving farms, while the VCS and ANC have stronger impacts on supporting profits (incomes). Both the BPS and AECM are associated with relatively strict land management conditions and hence additional costs, while the ANC and VCS, being linked to production, do not impose such additional costs.

The effects on structural change are considerably stronger if all four instruments are considered simultaneously (i.e., **CAP** scenario), with the number of farms declining by 15%, compared to 13% when summing across the individual scenarios; and the area of abandoned agricultural land increasing to 4251 ha compared to 62 ha as the simple sum across the individual instrument scenarios. This demonstrates that the instruments are mutually reinforcing, thus confirming our hypothesis that strong complementarities exist among the different instruments. While agriculture in the region will "survive" without any single instrument, it will likely be decimated by major simultaneous reductions in all four instruments.

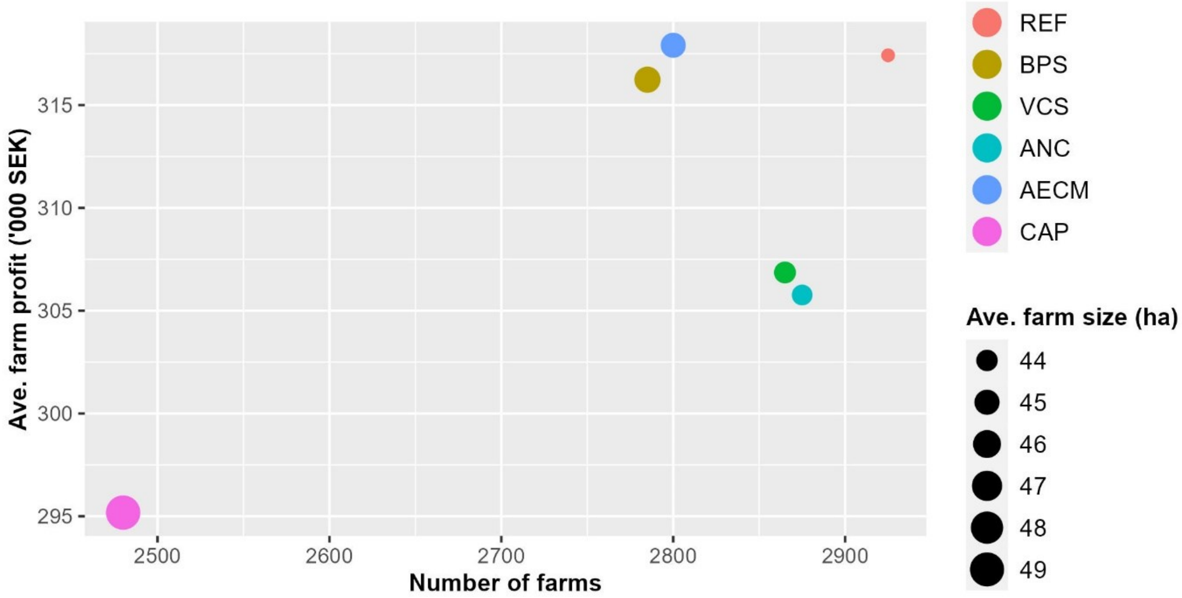

Figure 2. Effects of the different policy instruments on agricultural structure in terms of: Average farm profit, number of farms and average farm size in the study region.

All four instruments result in a certain degree of capitalization of payments in land rental prices, and hence all raise the value of maintaining land in agriculture (Figure 3). The relatively small impact of the VCS on semi-natural pasture rents implies that this instrument is least important for incentivizing the preservation of pastures, while the AECM clearly creates the strongest incentive compared to the other three. Interesting to note is that the AECM also has a relatively strong indirect impact on the arable rental price, because of the need for additional fodder to sustain grazing livestock over the winter. The BPS has a relatively strong impact on land rental prices compared to the VCS and ANC because it is tied directly to land. Given a main goal of the BPS is to support incomes, the partial capitalization of this payment in land values reduces its effectiveness as income support.

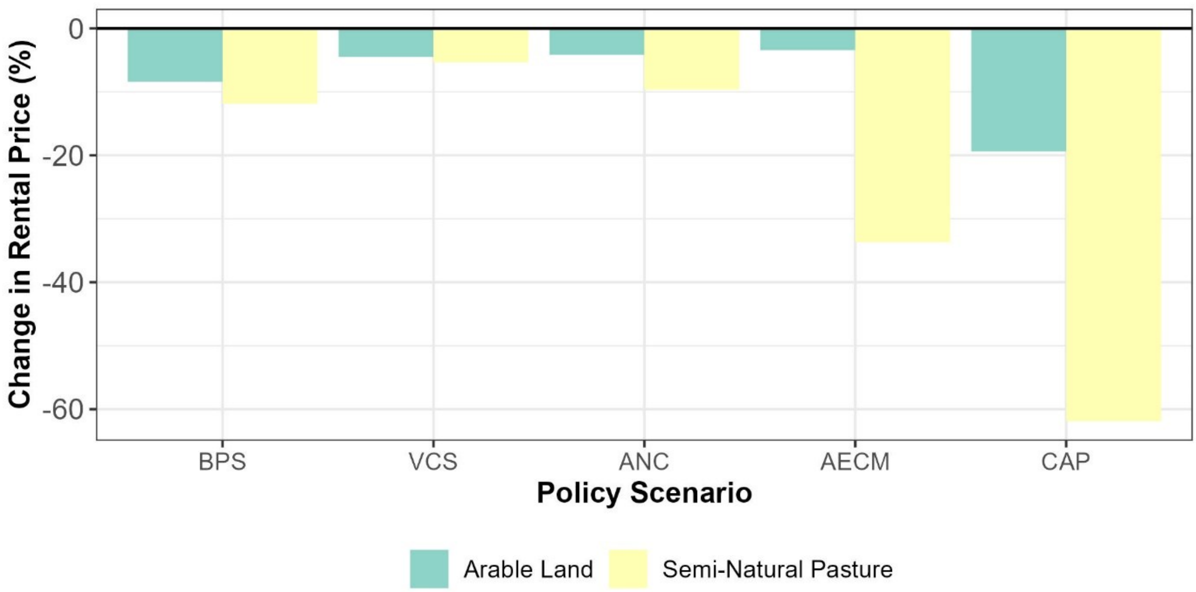

Figure 3. Effects of reducing payments on average land rental prices for arable land and semi-natural pastures compared to the Reference scenario in 2030.

6.1.2 Land use

The different instruments influence land use to varying degrees, reflecting the different conditions attached to payments (Figure 4). Reducing the ANC payment has a relatively large impact on the area of fallow since it promotes active agricultural uses, i.e., crop or fodder production. Congruently, reducing the BPS in presence of the other instruments primarily influences the area of arable crops and to a minor extent semi-natural pastures.

The AECM is shown to have a stronger effect on the preservation of pastures than any of the other instruments, which is a direct result of tying payments to preservation of pastures. The AECM also indirectly influences active use of arable land through complementary fodder production for the livestock used to maintain pastures. In contrast the VCS has only a marginal effect on the area of semi-natural pastures due to its indirect link to preservation via numbers of cattle. The ANC has a comparatively stronger impact on pastures than the VCS, because payments are linked indirectly to agricultural area via livestock density conditions.

Finally, reducing all payments simultaneously results in considerable increases in both the areas of fallow and abandoned land, as well as substantial reductions in the area of semi-natural pastures and productive arable land uses.

These results confirm the ANC's importance as an incentive to maintain agricultural production in HNV regions and the AECM to preserve pastures, with the BPS and VCS having the least effects in these respects.

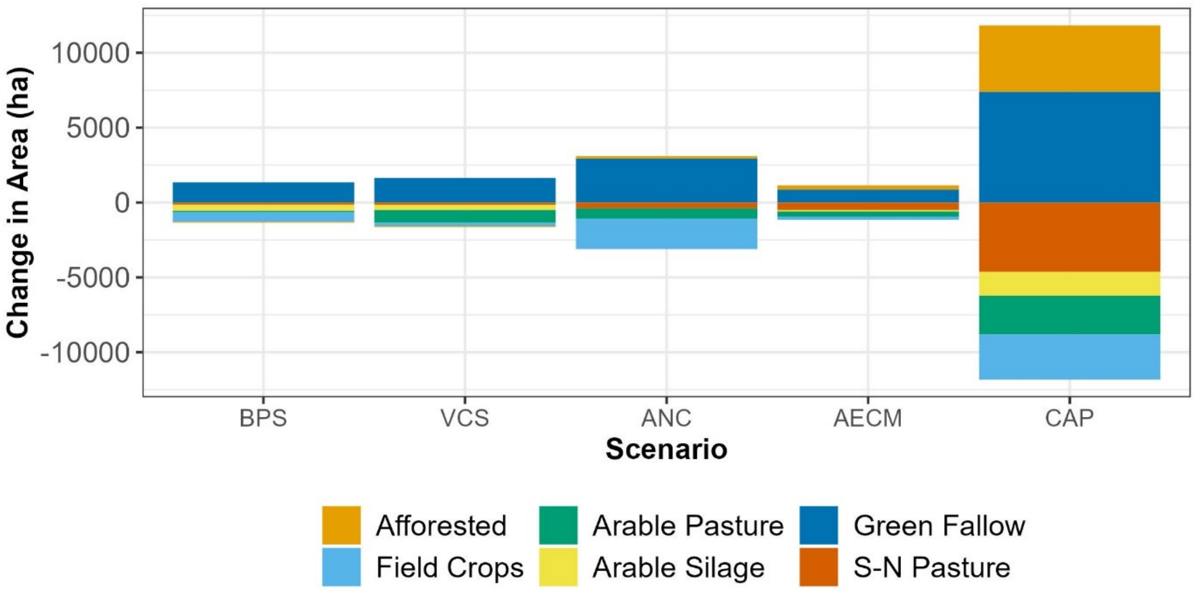

Figure 4. Effects of reducing payments on agricultural land use in the study region.

6.1.3 Livestock holdings

As expected, reducing the VCS results in fewer cattle in the region, but not livestock numbers in general (Figure 5). Since the VCS is only coupled to cattle, it has the effect of creating a strong substitution effect among livestock. Reducing the VCS therefore resulted in fewer cattle and more sheep for lamb production. Reducing the ANC payments results in the greatest net reduction in livestock numbers compared to the other three instruments, while reducing the AECM is shown to reduce the number of grazing livestock; sheep, and suckler cows and associated beef cattle. Thus, even the strongly land-use based ANC and AECM instruments have strong indirect effects on livestock numbers, which is mainly due to fodder production being the most profitable use of agricultural land in the region, particularly grasses, rather than food crops. Interestingly, dairy cows are least affected by any of the policy instruments, due to the fact that policy payments constitute a relatively small portion of total revenues from milk production.

Simultaneously reducing all four payment types, results in considerable reductions in beef, suckler cow and sheep production, indicating their relative dependence on CAP support, compared to dairy production.

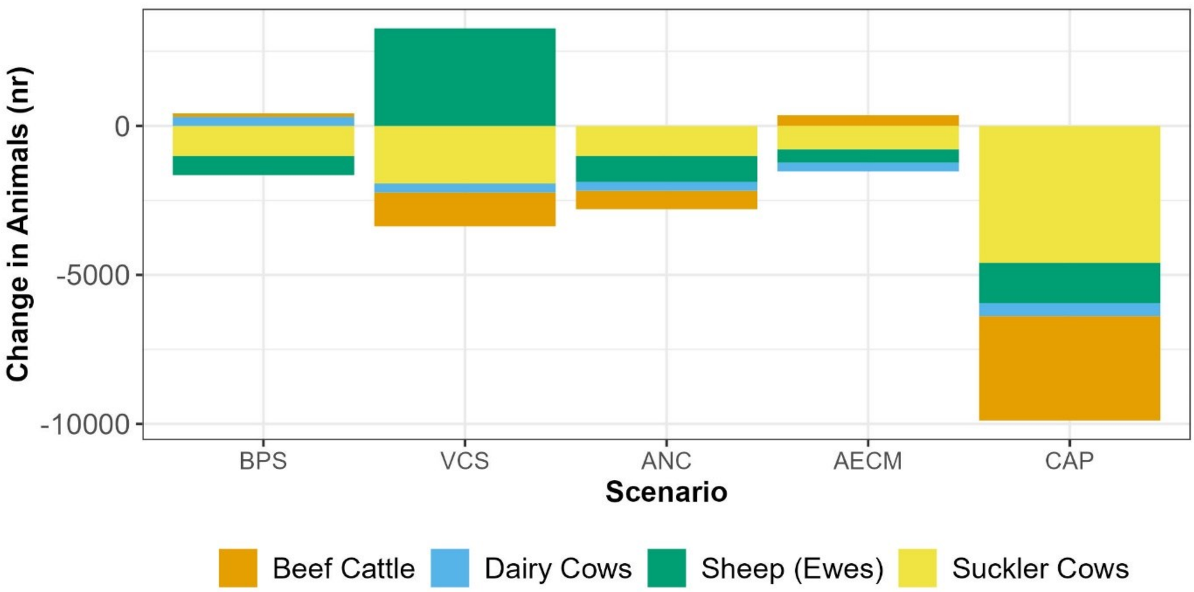

Figure 5. Effects of reducing payments on livestock numbers in the study region.

6.2 Semi-natural pastures, climate and food production

The VCS and ANC payments are shown to have the strongest impacts on enteric methane emissions and food production, while the ANC and AECM have the largest impacts on the area of pastures (**Figure 6**). (Recall that these results are for partial reductions in individual payments and not all the payments, Table 2, except for the AECM). Interestingly, reducing the BPS results in lower methane emissions and area of pastures, but higher food production thanks to an increase in the production of food grains and milk, as well as less land devoted to extensive fodder production. Consequently, the different instruments are shown to have varying impacts in magnitude on these indicators.

The collected impacts of all four instruments are pervasive (CAP scenario, **Figure 6**), resulting in far more food and pasture, but also higher methane emissions than otherwise would be the case due to widespread agricultural land abandonment. This indicates that the different instruments have strong complementary effects.

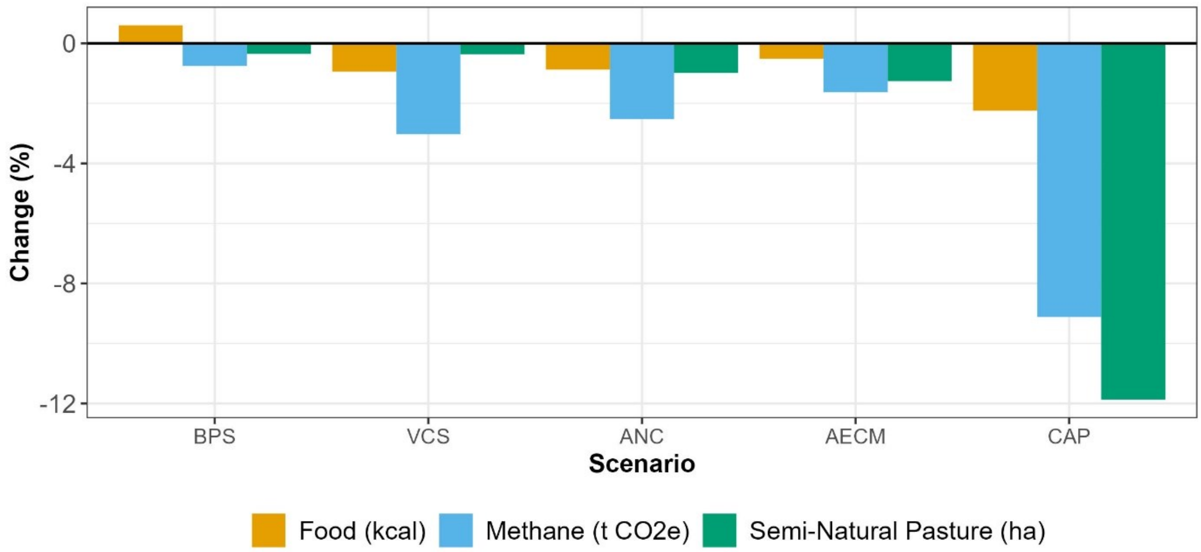

Figure 6. Impacts of the different policy instruments on food production, enteric methane gas emissions and conservation of biodiversity (area of semi-natural pastures) in the study region.

As an alternative way of assessing the impacts of the different instruments in relation to conflicting policy goals, we present in **Figure 7** the cost in terms of environmental efficiency, i.e., the additional methane emissions of preserving an additional hectare of pasture or producing an additional unit of food for each instrument. Clearly, the VCS is least 'efficient' for preserving pastures in terms of methane emissions, and the AECM most efficient. The high unit cost of the VCS in terms of methane emissions, confirms its weakness as an instrument to balance multiple policy goals. The ANC on the other hand delivers a better balance between food production and preservation of pastures than the VCS in terms of methane emissions.

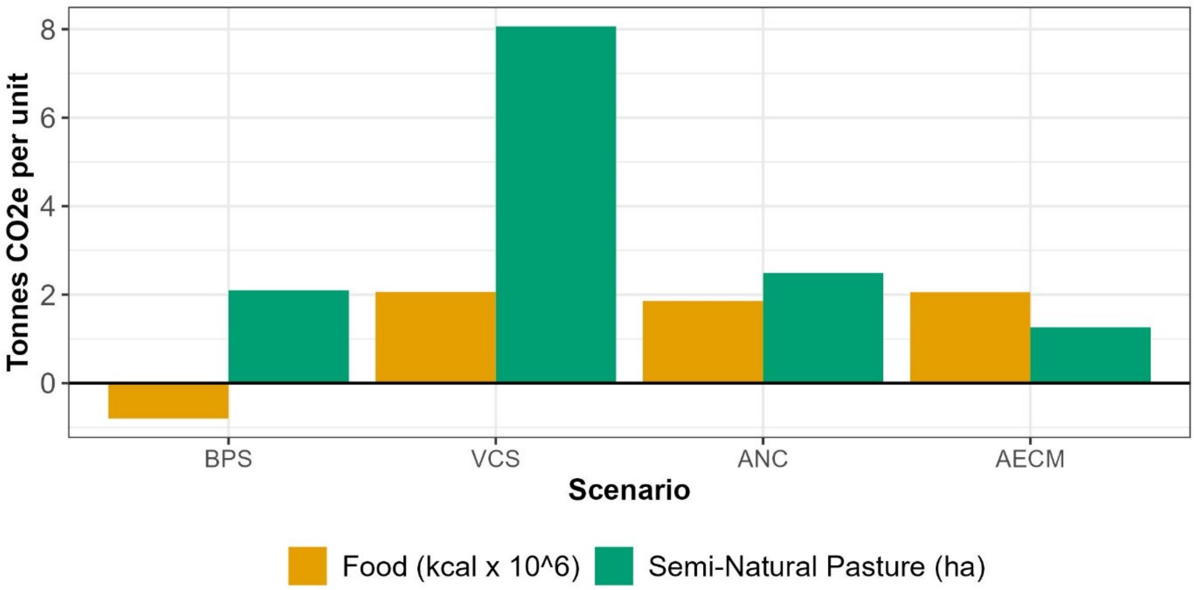

Figure 7. Environmental efficiency of the different policy instruments in terms of biodiversity (area of semi-natural pastures) and food production per unit methane emissions in the study region (i.e., the additional CO2e methane emissions per unit of pasture or food).

7 Discussion

The EU's Common Agricultural Policy (CAP) has broadened over recent decades in response to evolving global challenges. It now claims to support not only food security and farmers' incomes, but also transitioning to a green economy, conservation of biodiversity and climate action. A fundamental tenet from the theory of economic policy is that multiple policy goals require multiple policy instruments; one instrument for each (uncorrelated) goal. If there are more instruments than goals then some instruments will be redundant. Given this background, we have evaluated to what extent four of the main types of CAP instruments form a cohesive and effective package for achieving policy goals in regions dominated by HNV farming, which are crucial for the provisioning of public goods in the EU.

Each of the evaluated instruments was shown to influence the evolution of farm structure, land use, livestock holdings, methane emissions from ruminants, biodiversity (semi-natural *pastures*) and food production, but variably and to substantially different degrees. No single instrument could meet all goals simultaneously, but some were found to be more effective in terms of minimizing methane emissions per unit area preserved pastures or calories produced food. In particular the environmental payment to pastures (AECM) was found to be far more environmentally effective for preserving pastures than the coupled livestock payment (VCS), while the area-with-natural-constraints payment (ANC) performed better in this respect than the VCS, as well as in generating food production. Overall, the BPS had least impacts on the evaluated societal variables, indicating its role as a foundational income payment, decoupled from production.

When considering all four instruments simultaneously, their collective impacts were found to be ubiquitous for sustaining farming in the region, without which semi-natural pastures and food production in the region would be severely impacted (Figure 6). Hence, our results demonstrate that the current system of payments in its entirety is vital for maintaining farming and biodiversity in HNV regions, but that they also drive climate-warming emissions.

Instruments coupled to production, such as the VCS, was shown to be ineffective for balancing environmental trade-offs, because there is no mechanism to ensure that the environmental trade-offs are sufficiently considered by farmers. This indicates that the system could be better designed to maintain farming and conserve biodiversity, while reducing methane gas emissions, through a better distribution of total payments among the evaluated instruments (i.e., optimizing the mix of payments according to policy goals).

7.1 Significance of findings

To be environmentally cost-effective, a policy instrument needs to be closely linked to the desired outcome, e.g., preserved pastures or reduced emissions (Wätzold*, et al.*, 2016), which our evaluation of the AECM corroborates. Furthermore, our results indicate that another reason for the CAP not achieving its environmental objectives could be that policymakers are not taking into account the long-term impacts of the type of instruments chosen via their interplay with structural change, to achieve multiple policy objectives. For instance, one can immediately appreciate that the preservation of semi-natural pastures depends on continued grazing by ruminants, such as cattle. However, it is not immediately apparent that coupled livestock payments (e.g., VCS) are not necessary for maintaining the biodiversity associated with these pastures.

While our modelling confirms that links between production and public goods exist (jointness in production), we even show that the VCS was the most ineffective instrument for balancing multiple goals. In fact, as the evaluation of the AECM instrument demonstrated the preservation of pastures can be more effectively secured through targeting payments on the desired environmental outcome, in this case the grazing of pastures. A result we expect to hold for any manner of environmental impact.

Our results also demonstrated that it is crucial for the conservation of biodiversity and other public goods such as the cultural landscape that HNV areas such as our study region, continue to be supported. On the other hand, their relative reliance on livestock production results also in negative environmental impacts, particularly methane gas emissions. This complexity makes theoretical resolution of the appropriate policy response difficult. While grazing by livestock is necessary to preserve pastures there exists considerable flexibility in the agricultural structure that can provide this service, but with lower emissions rates. It could be a dairy farm, a beef farm, a sheep farm or even a grazing-services business that shuttles bred-for-purpose cattle around the countryside (Boke Olén*, et al.*, 2021). Accordingly, one must carefully consider the relationship between the choice of farming system and technology as well as unintended effects, before a claim of jointness to motivate coupled payments can be made. Our study corroborates the evidence that public goods associated with agriculture are not joint with commodity production per se, but rather with land use practices and agricultural structures (Abler, 2004).

7.2 Policy implications

In light of our findings, it seems that two of the evaluated instruments BPS and VCS (so-called direct payments) could be reduced to improve goal achievement (as suggested by Harvey*, et al.* (2017)), while ANC and AECM payments could be strengthened to achieve better environmental outcomes and continuation of food production in HNV regions. The ANC also has a stronger effect on incomes and maintaining farms than the BPS (Figure 2).

Since coupled payments reward farmers for having cattle per se and only indirectly for preserving biodiversity, the VCS results in far more cattle than are necessary when considering other goals such as climate action and avoiding production surpluses; because over time farmers are provided with an incentive to hold more cattle than are needed to maintain the limited area of semi-natural pastures.

Indeed it has been found that farms adapt their numbers of livestock very quickly to policy interventions (Kirchweger and Kantelhardt, 2015). Such an instrument therefore does not simply preserve the status quo, as is usually intended, but as shown here, also acts on agricultural structure to generate unintended effects (i.e., too many cattle); and ultimately, agricultural policy failure.

Our results indicate that there exist sufficient agricultural substitution possibilities within the studied HNV region to maintain food production and preserve biodiversity while reducing methane gas emissions. This is because different livestock types and feed production activities have different needs for pasture based fodder (which is related to biodiversity conservation) and food output measured in calories. This suggests considerable scope exists for optimization of these policy instruments and the introduction of others to minimize environmental and food-production trade-offs. For example Himics*, et al.* (2020) investigate the impacts of converting the current BPS to a payment based on reductions in farms' GHG emissions. Innovative contract designs have also been suggested for implementing result-based schemes (Olivieri*, et al.*, 2021).

7.3 Limitations

Our study has a number of limitations due to it being based on a relatively small study region compared to the entire area of HNV regions in the EU. In particular, prices are held constant in all simulations. If instead the evaluation was carried out at the EU level, we could expect sufficiently large changes in production to impact market prices, which could moderate or exacerbate the impacts of each instrument on the chosen evaluation criterion. Furthermore, our analysis is based on simulations whereby farm-agent behaviour is modelled using normative mathematical programming, which does not allow the quantification of uncertainty. Nevertheless, our simulation model was validated to observed structural change in the region ensuring that it adequately reproduced observed trends in farm structure, land use and livestock holdings over the validation period (2016-21).

7.4 Future Research Directions:

Considering, the existence of substitution possibilities and an already complex policy instrument mix, it would be interesting to study whether a better balance among policy goals could be achieved by simplifying the current policy mix and optimizing the payment budget across the necessary payment instruments. For instance, a first step would be to investigate the potential to remove the VCS (in the entire EU) and negate potential negative impacts on biodiversity and food production by increasing the payment level of one of the remaining instruments (i.e., ANC or AECM). Better still, would be to investigate the potential to have a greater share of support being targeted to public goods through a result-based payment system (Bartkowski*, et al.*, 2021), as has been made possible through the introduction of Eco-schemes in the 2023-28 CAP programme. In the study region the AECM is to a certain extent targeted on environmental performance, in that semi-natural pastures need to be grazed to a certain sward height and are differentiated into two payment levels based on biological qualities. This system, as indicated by our results, generates relatively low trade-offs with methane emissions and food production. Perhaps the ANC or BPC could be refined to better reflect environmental outcomes. Indeed, these are important questions for future research.

8 Conclusions

Our study finds that CAP payments are vital for achieving policy goals for agriculture in HNV farming regions, but the complex mix of policy instruments hides the potential for achieving optimal trade-offs among policy goals. Instead of comprising a coherent response to policy goals, the current mixture of instruments represents a patchwork of responses to potentially conflicting goals. Our study indicates great potential to optimize the policy mix to achieve a better balance between policy goals. Specifically, we draw the following conclusions:

- Overall, the BPS has least impact on the evaluated policy-impact indicators, including its prime goal, farm incomes.
- AECM payments to semi-natural pastures best preserves biodiversity and has the lowest climate impact per hectare of preserved pasture.
- The overall goal fulfilment of the VCS cattle payments is worse than other supports when its environmental effects are taken into account.
- It is possible to improve agricultural policy for HNV areas through the redistribution of funds between the evaluated payment schemes.

The vulnerability of HNV farming to market forces is, on the whole, generally recognised by farmers, consumers and policymakers within the EU. On the other hand, other more intensively farmed regions are quite competitive on the global market, but cause widespread environmental damage rather than substantial levels of public goods. Accordingly, if the multiple goals of EU agriculture are to be achieved cost-effectively through appropriate policy design, it is essential to recognise that European agriculture is highly diverse—not only in its commodity production and associated production systems, but also in its competitiveness, and impacts on the environment and public goods. We hope our study can contribute to the selection of instruments that are better adapted to the provisioning of public goods by HNV farming systems.

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