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Impacts of the EU's Common Agricultural Policy “Greening” reform on agricultural development, biodiversity, and ecosystem services

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Featured Article

Impacts of the EU's Common Agricultural Policy "Greening" Reform on Agricultural Development, Biodiversity, and Ecosystem Services

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Abstract *The EU's Common Agricultural Policy (CAP) has had limited success in mitigating agriculture's environmental degradation. In this paper we simulate the impacts of the 2013 "greening" reform on biodiversity and ecosystem services in environmentally contrasting landscapes. We do this by integrating an agent-based model of structural change with spatial ecological production functions, and show that the reform will likely fail to deliver substantial environmental benefits. Our study implies that greening measures need to be tailored to local conditions and priorities, to generate environmental improvements. Such spatial targeting of measures is though incompatible with the design of a common direct payments scheme.*

Key words: agent-based modeling, biodiversity, CAP reform, Ecological Focus Areas (EFA), ecosystem services, landscape, spatial production functions.

JEL codes: C610, Q180, Q570.

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Introduction

Agricultural intensification in Europe has resulted in loss of farmland biodiversity and degradation of ecological processes (Kleijn et al. 2009). This poses significant risks, not only for the conservation of biodiversity, but also for ecosystem services that underpin agricultural productivity, such as the pollination of flowering crops and biological control of crop pests by their natural enemies (Potts et al. 2016). The EU's Common Agricultural Policy (CAP) has, in line with its original objectives, facilitated agricultural intensification in the past (Lefebvre, Espinosa, and Gomez y Paloma 2012). Today, access to CAP payments and the EU's internal market is driving intensification in new member states from the former Eastern Bloc (Pe'er et al. 2014). Attempts to mitigate negative environmental impacts of intensification have been made through major reforms in 1992 and 2003, most ambitiously in the 2013 reform through the introduction of "greening" measures (European Commission 2013a). However, the environmental effectiveness of the 2013 reform is heavily debated (Pe'er et al. 2014; Alons 2017).

The combination of national and farm-level flexibility in choices of greening measures, broad exemptions for certain types of farms and regions, complex interactions with the environment, and interactions with other components of the reform, make it far from straightforward to assess the impacts. In this paper, we simulate how the major elements of the 2013 reform are likely to impact agricultural structure, land use, and biodiversity and ecosystem services in two contrasting regions. These regions are representative of variation in agricultural and environmental conditions typical for the EU.

Several studies have attempted to analyze the effects of the greening measures. Waś, Zawalińska, and Britz (2014) predict that these measures will have a limited impact on agricultural development, with small improvements in the environmental status of the evaluated member states. Similarly Gocht et al. (2017) predict limited economic and environmental impacts at the EU level. In terms of biodiversity and ecosystem services, Angileri et al. (2017) estimated the potential impacts at the county level across member states. They conclude that the impacts will mainly depend on the area of each type of greening measure implemented on farms. Specifically, that biodiversity and ecosystem services are likely to improve in regions where the landscape-feature measures, hedges and buffer strips, represent more than 50% of the area devoted to greening measures.

However, the environmental assessments have been done at a coarsely aggregated level and none of them consider farm-specific characteristics (type of production, farm size, factor endowments, technology, location, *etc.*) or the landscape context (where measures are taken), which is crucial for predicting impacts on biodiversity and ecosystem services (Ekroos et al. 2016). In addition, their focus has been on the greening measures per se, while ignoring interactions with other major reform elements. For instance changes in payment rates are also likely to affect farmers' land-use responses to the reform, and thereby have indirect effects on biodiversity and ecosystem services.

A number of studies capture interactions between the reform elements, but do not consider environmental impacts. Using an individual farm approach, Espinosa et al. (2019) quantify the impacts of the major reform elements on farmers' incomes and production, while Louhichi et al. (2018) focus on the distributional effects. In addition, Ciaian, Kancs, and Swinnen (2019) analyse the effects of the reform, but focus on capitalisation effects. Accordingly, there is a

need to understand the overall effects of the reform and how these might translate into environmental benefits. To do this, spatially explicit ecological-economic modeling is required.

We extend and apply the agent-based AgriPoliS model of endogenous structural change (Balmann 1997; Happe, Kellermann, and Balmann 2006), to simulate the impacts of the major components of the 2013 reform on farmers' land use. We then link simulated land-use changes to a spatial ecological production function that can predict the impacts on biodiversity, pollination, and biological control of pests by their natural enemies, hereafter biological control (Häussler et al. 2017). AgriPoliS has successfully simulated the dynamic impacts of CAP reform on agricultural structure (Happe et al. 2008; Brady et al. 2017) and the environment (Piorr et al. 2009; Brady et al. 2012). A particular advantage of AgriPoliS relative to other economic models used to evaluate CAP reform such as CAPRI (Gocht et al. 2017) or IFM-CAP (Louhichi et al. 2018), is that it captures interactions among farms on an endogenous land market and spatial variability in farm characteristics.

Using this innovative ecological-economic approach, combined with a comparative study of effects in two agriculturally and environmentally contrasting regions, we were able to determine how well the current greening measures cater to farm and regional characteristics, and their interactions with the other reform components. To gauge the potential for improving the environmental effectiveness of the CAP through so-called greening measures, we also simulated more ambitious "greening" scenarios.

EU's Common Agricultural Policy (CAP)

The European Union (EU) has developed an internal market for its 28 member states to allow the free movement of people, goods, services, and capital within its borders, including agricultural products. The CAP was introduced in 1957 in the aftermath of WWII to ensure food security, modernize agriculture, improve the livelihoods of farmers and stabilize food prices through common financing and regulations.

Over its first decades, price support was provided through market regulating activities. This focus on support to production resulted eventually in extreme levels of overproduction ("lakes of milk and butter mountains") in the 1970s and 1980s. These were disposed of through dumping on world markets, but even physical destruction occurred. Because of the resultant distortions of world food markets and moral outrage, the EU introduced milk quotas in 1984 and was forced onto a path toward the decoupling of support from production, beginning with the McSharry reform in 1992. The principal ingredient of this first reform was to move from market regulating activities to direct payments to farmers based on areas of eligible crops and numbers of eligible livestock, rather than indirectly through product prices. Since direct payments were not dependent on the volume of production these contributed to reducing overproduction, but not to the extent needed. For one thing, farmers were still required to produce commodities, and for another, the obligation to take some land out of production (set-aside) resulted only in their least productive land being taken out of production, which was exacerbated over time by dynamic adjustments in land holdings by farmers (Rygnestad and Fraser 1996).

During the 1990s environmental issues and climate change also gained in importance. Further, the expansion of the EU from six states to a more heterogeneous 15 states in 1995 generated the need for greater flexibility among

member states to determine some policy responses at the national level, such as environmental measures, due to the spatial variability in conditions across the EU. The Agenda 2000 reform therefore strengthened the CAP's market orientation by increasing the proportion of direct payments and tightening milk quotas. It also separated the CAP into two pillars where remaining market interventions and direct payments were categorized into Pillar I, while Pillar II widened the policy sphere to rural development, in particular through payments to farmers for implementing voluntary environmental measures (agri-environment schemes), investment subsidies and support to small-scale development projects.

Still, these reforms were insufficient to stave WTO criticism of remaining trade distortions and citizens' environmental concerns (Phelps 2007). This paved the way to the most radical reform to date, the Mid-Term Review or 2003 Reform, which decoupled the majority of direct payments from production (Cunha and Swinbank 2011). Commencing in 2005, the EU's farmers have not been required to produce agricultural commodities to receive these direct payments that are based on their agricultural area; as long as they keep their land in "good agricultural and environmental condition," which is intended to avoid the abandonment of agricultural land. "Good condition" is stipulated in standards established by the member states, such as keeping the land free of trees and bushes, and maintaining tile drainage systems. Further, failure to comply with legislation relating to the protection of the environment, animal welfare, and food safety ("statutory management requirements") can result in reductions of payments. These two strands of prerequisites for payments are referred to as *cross-compliance*. Decoupling was a success in the sense that EU agriculture is now more or less market-driven and overproduction primarily eliminated (OECD 2011).

A remaining problem with direct payments, however, was that rates of decoupled payments varied substantially among and within member states (European Commission 2013b). Rates in marginal agricultural areas and in states joining the EU after 2005 (i.e. former Eastern Bloc countries) were generally lower than in existing member states. The former variation due to historical bias, since rates of direct payments introduced with the 1992 reform were derived from support levels based on price support and normal yields, hence higher yields giving higher direct area payments. Further, when livestock headage payments were decoupled in 2005 many states, including Sweden, chose, as was allowed, to convert portions of these to a farm-specific decoupled payment. As a result, substantial variation emerged in the per hectare payment rates among farms. Even farms that ceased with livestock production after 2005 retained the right to their farm-specific payments. As direct payments have an aim of providing income support, this imbalance was perceived as not only unfair, but incongruent with CAP objectives. Finally, the environmental performance of the agricultural sector was still subject to considerable criticism.

The 2013 reform intended therefore to even out payments among and within member states, referred to as external and internal convergence respectively (European Commission 2013b). To offset the expected large redistribution of payments among farmers and regions, primarily from livestock to arable farms, the possibility of introducing Voluntary Coupled Support "to secure the future of potentially vulnerable sectors" was also created, but limited to 13% of each state's direct-payments envelope. The reform also intended to improve environmental performance by attaching

specific environmental obligations to 30% of their envelope, so-called green direct payments, hence the designation “greening” reform.

Over the period 2014–2020 the CAP accounts for 37.8% of the EU budget or €362.8 billion (Chemnitz 2014). Of this, 72% goes into direct payments, of which 90% are decoupled from production; 5% into Pillar I market management, compared to 90% of the CAP budget in 1992; and 23% into Pillar II schemes of which 30% should be reserved for voluntary measures that are beneficial for the environment and for combating climate change. In order to receive full direct payments in the form of the Basic Payment Scheme, farmers have since 2015 been obligated, in addition to cross-compliance, to fulfill greening measures related to: (i) crop diversification; (ii) having some of their agricultural land as seminatural habitat, called Ecological Focus Area (EFA); and (iii) maintaining existing permanent grassland (EU 2013).

The crop diversification measure aims to improve soil quality by discouraging monocultures. Specifically, by requiring farms to grow a minimum of three crops on their arable land, where any one crop may not cover more than 75% of a farm’s area, and any two crops not more than 95% of the area. In practice, the crop-diversity measure will only affect a relatively small subset of farmers, as most farms in the EU already meet the requirement (Westhoek et al. 2012).

The EFA measure requires farms to manage at least 5% of their arable land as seminatural habitat, primarily to safeguard and improve biodiversity on farms. There are 10 types of land-use options specified in Article 46 of the regulation that qualify as EFA: (i) fallow land, (ii) terraces, (iii) landscape features such as hedges, (iv) uncropped field margins or buffer strips, (v) agro-forestry, (vi) strips along forest edges, (vii) short rotation coppice, (viii) afforested areas, (ix) catch crops or green cover, and (x) nitrogen-fixing crops. Each member state has though the flexibility to exclude particular measures available to their farmers and make use of a system of conversion or *weighting* factors when determining whether a farm satisfies the EFA requirement. This implies that the actual proportion of EFA on any particular farm could be greater than or less than the 5% of the farm’s area as stipulated in the reform, depending on the farmer’s current land-use and choices of EFA types.

In practice, preservation of grasslands is not a farm-level constraint, but applies at the national level, whereby each member state is required to limit declines in the ratio of permanent grassland to their total agricultural area, to a maximum of 5% relative to the 2015 areas. They are also required to designate and protect their most environmentally sensitive grasslands from plowing to support carbon sequestration, and protect biodiversity and soils.

Finally, the greening measures do not apply to all farms, due to broad exemptions based on farm characteristics. For instance small farms (those less than 15 ha) and farms where more than 75% of their arable area is used for the production of grasses, or organic farms and farms in forest-dominated regions, are exempt from the diversification and EFA measures. Consequently, we focus on the EFA measure because of its broad applicability to EU farmers and potential for generating biodiversity benefits.

Methods: Integrated Economic and Ecological Modeling

In this section we first introduce the study regions and then describe the economic and ecological modeling procedures, which had the following main steps (figure S2 Supporting Materials):

- I. Extend AgriPoliS to model major reform components: (i) equalization of direct payments, (ii) green direct payment, (iii) voluntary coupled direct payment, and (iv) Ecological Focus Areas.
- II. Calibrate AgriPoliS to the study regions and validate baseline results with reality.
- III. Perform policy scenario analysis of 2013 reform with AgriPoliS.
- IV. Translate AgriPoliS output to spatially explicit land-use information and link to ecological production functions.
- V. Use ecological modeling to evaluate environmental impacts on: (i) bird biodiversity, (ii) biological control, and (iii) pollination.

Study Regions

We simulated the effects of the 2013 reform in two contrasting agricultural regions in Sweden, Götalands mellanbygder (GMB) and Götalands södra slättbygder (GSS) (figures 1a and 1b). Natural conditions in the study regions are relatively homogeneous within the regions, but vary between them. Both are characterized by intensive farming and major production activities found throughout the EU (wheat, barley, oilseed and sugar beet, as well as substantial grass fodder production in GMB; and the livestock types: dairy and suckler cows, beef cattle, pigs, and sheep). Land use is also dominated by agriculture and farms over 15 ha, hence the EFA measure is applicable to most farms in the regions.

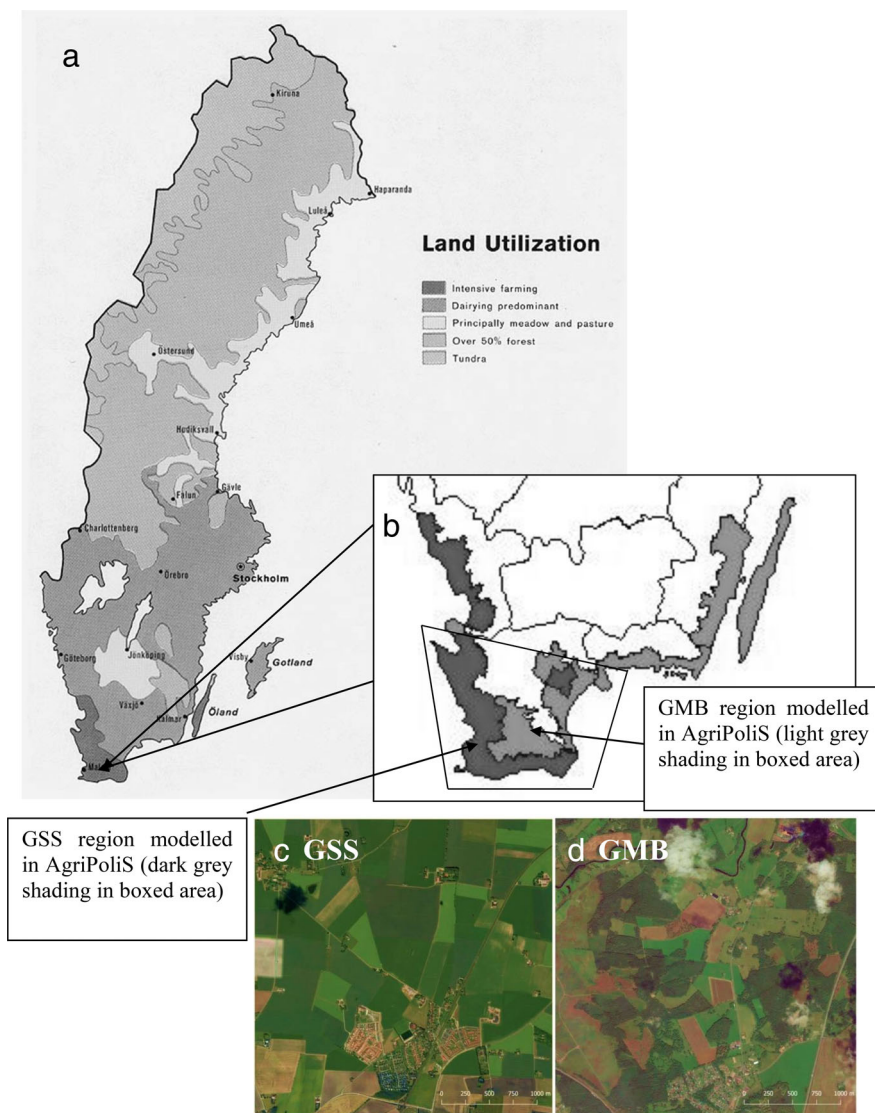
The regions differ, however, in landscape characteristics and production specializations. GSS has a homogeneous landscape with large, interconnected arable fields and a relatively small area of pastures and other seminatural habitats (figure 1c). GMB, in contrast, has a heterogeneous landscape with relatively small, fragmented fields that are generally separated by other land uses such as forest and seminatural habitat (figure 1d). Crop yields are around 20% higher and farms 10% larger in GSS than in GMB (see table S1 Supporting Materials for comparison of agricultural structures). Farms in GSS are primarily arable cropping specialists, while livestock specialists dominate GMB, where land use is a mixture of arable cropping and grassland (both seminatural pastures of high biological value and arable leys).

The study regions are representative of conditions frequently found in the EU. For instance, GMB has similarities to northeastern Germany, western France, the Danish peninsula, and northern Austria, which are also mixed farming regions characterized by a relatively heterogeneous landscape and medium input intensity, as well as having substantial areas of High Nature Value farmland (HNV), i.e. farmland designated to have high biodiversity value. GSS on the other hand has similarities to areas in north central France, southeast England, and the Danish isles, as these are characterized by a relatively homogeneous landscape and farming is dominated by specialized, high-intensity cropping, with little or no HNV farmland. Consequently, the impacts identified in the case study regions may be generalized to large areas of the EU, and crucially, can illustrate the implications of spatial variability for the potential environmental effectiveness of common greening measures.

Economic Modeling with AgriPoliS

AgriPoliS simulates the behavior of a heterogeneous population of income maximizing farm-agents (individual farms) that interact through competition

Figure 1 a) Map of Sweden showing major agricultural land uses and location of the study regions. b) Map of southern Sweden showing study areas modeled in AgriPoliS and representative aerial photographs of typical landscape segments in each region. c) GSS has a homogeneous landscape that is dominated by large arable fields and d) GMB has a heterogeneous landscape dominated by a mosaic of smaller arable fields, grassland and forest. Source: Nation Master (2018), Statistics Sweden (2014), Google Maps (2017) [Color figure can be viewed at wileyonlinelibrary.com]



for land on an endogenous land-rental market (see Kellermann et al. (2008) for full model documentation). The model is both dynamic and spatial. It models the strategic decision whether to continue farming, or close down and release land to the land market at the start of each year in the simulation period (2014–2020). Farms can also grow if other farms release land to the land market and invest in larger capacities of machinery and stables to reduce costs, or downsize. The AgriPoliS landscape is a two-dimensional grid that represents the spatial distribution of farms and fields in the region according to the

statistical properties of the real landscape, e.g., the distribution of field sizes and distances of fields to farm centers (Brady et al. 2012). Consequently, Agri-PoliS can simulate the process of structural adjustment to a major change in the policy environment at a micro and spatially explicit level, which is central for evaluating environmental impacts (Wätzold et al. 2016).

The modeled GSS and GMB regions are based on a selection of typical farms sourced from an annual survey of real farms in the regions *via* the EU's Farm Accountancy Data Network or FADN, that were subsequently scaled up to represent the entire population of farms in the real region (see Hristov et al. (2017) for documentation). Farmers' ages and the vintages of fixed assets are initialized randomly. The production activities available to the resulting heterogeneous farm agents and their income optimization problem are modeled using Mixed Integer Programming (MIP).

Given that the mathematical structure of the model is specified in Kellermann et al. (2008) we provide here a very general or pseudorepresentation of the farm-agents' optimization problem. Each farm agent maximizes its family income (Y) by optimizing the choice vector \mathbf{X} , given prices for outputs (\mathbf{p}) and variable costs of inputs (\mathbf{c}):

$$\max_{\mathbf{X}} Y = (\mathbf{p} - \mathbf{c})\mathbf{X} + DP + VCS + IR + W - RE - IC - HW - TC - MC - D$$

subject to

$$\mathbf{r}\mathbf{X} \leq \mathbf{b} \text{ and } \mathbf{X} \geq 0,$$

where \mathbf{r} is a matrix of technological, resource, and institutional constraint coefficients, and \mathbf{b} is a vector of resource capacities (farmland area, own labor, *etc.*) or other values necessary to implement relevant constraints on the farm agents' decision space.

The activity choices \mathbf{X} include not only land-use (i.e. crops and EFAs) and livestock numbers, but also activities relating to financing, land holdings, and the allocation of own capital and family labor on or off the farm, as well as investments in machinery and stables (the integer activities). Farm income and hence strategic decisions, are also affected by policy payments linked to a farm's land area, specifically, decoupled direct payments including the greening component (DP) and voluntary coupled support (VCS) based on the number of eligible livestock, where both also depend on meeting the cross-compliance conditions, and the green payment on meeting the EFA obligation as well. Further, they have potential revenues in the form of interest received on liquid capital (IR) and wages from working off the farm (W). Farm agents also have joint costs depending on the farm's size, loans, and labor needs, these being: land rental expenses (RE), interest paid on borrowed capital (IC), and wages paid for hired labour (HW), as well as transport costs (TC) related to the distance of fields from the farm centre where machinery and livestock are housed. Finally, there are fixed costs in the form of the maintenance (MC) and depreciation (D) of fixed assets, that are treated as sunk once an investment is made (i.e. assumed to have no alternative value than in agriculture).

A farm will quit if the expected income for the coming year fails to cover variable costs and opportunity costs for their own factors, the farm is insolvent or because a successor does not exist when the farm agent reaches the retirement age of 65. The opportunity cost of family labor is valued at the off-farm income level (implicit in W), capital at the long-term interest rate

(as used to calculate *IR*), and owned land at the average regional land rental price.

We modeled the major components of the 2013 reform. Phase-in of the new equalized basic direct payment to 193 €/ha in 2019 and VCS payment of €91/head of cattle were modeled using existing functionality. To model the green direct payment of €58/ha and EFA obligation we extended the MIP tableau according to table S2 in the Supplementary Materials.

The types of EFAs allowed in Sweden and their designated weighting factors are respectively (SVJ 2015): (i) fallow land (weighting 1.0); (ii) field margins (9 times the length of a strip, which must be at least 1 meter wide); (iii) short rotation coppice, i.e. willow (0.3); (iv) undersown crops or catch crops (0.3); and (v) nitrogen-fixing crops (0.7). The weights are intended to reflect how much each EFA is likely to enhance biodiversity relative to fallow land. For example, a weighting of 0.3 means that farmers must allocate 3.3 ha to the relevant EFA type to count as 1 ha EFA.

The reform places no constraints on where farmers can place their EFAs, other than on their farmland. To capture the major source of observed differences in soil productivity across the regions (soils suitable for cash crop production or lower-value fodder production), we classify arable land pixels in the AgriPoliS landscape as either having high or low productivity, where productivity is relatively higher in GSS than GMB for each type.

When faced with the new EFA requirement, each farm agent chooses the type and placement of EFAs that suffice to meet the formal requirements, while minimizing the negative impact on farm income. AgriPoliS also captures the potential to rent additional (low productive) land to meet the requirement or change the structure of their production. AgriPoliS reproduced well the observed trends in the number of farms, land use, livestock holdings, and EFA areas observed in 2015 (see Supporting Materials, Validate AgriPoliS results with reality).

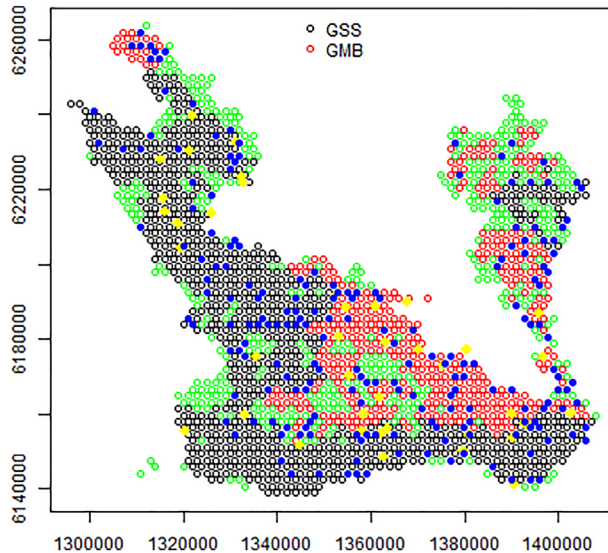
Ecological Modeling

We used spatially explicit ecosystem-service production functions to translate land-use changes predicted by AgriPoliS to consequences for biodiversity, pollination, and biological control. Crop cover and EFA predictions from the AgriPoliS simulations were downscaled to raster layers of the two production regions. Landscape realizations were based on a prereform 2014 raster layer. The rasters had a resolution of 25×25 m developed from spatially explicit information on field positions and crop cover from the Swedish implementation of the European Integrated Administration and Control System (IACS) and its geographical module LPIS (Sagris, Kikas, and Angileri 2015), complemented by nonagricultural land-use information obtained from the Swedish CORINE Land Cover Database (Svenska Marktäckedata, SMD).

Two downscaling steps were repeated until the total area of crops matched the boundary conditions, set up by the prediction from AgriPoliS under a particular scenario. Three samples of possible realizations were produced to exclude that differences between scenarios were due to chance, i.e., the random landscape realization.

The impact analyses of the scenarios were conducted at the landscape level, by dividing the two regions into nonoverlapping 1 km radius circular landscapes covering the majority of the agricultural area in each region: 1089 for GSS and 673 for GMB (figure 2). Regional landscape heterogeneity was

Figure 2 Landscapes included in the impact assessment (black – GSS, red – GMB, green –excluded from the analysis, yellow – study landscapes used to estimate parameters in the biodiversity production function, blue – sampled landscapes used to test the influence of landscape heterogeneity on the effects of the 2013 reform on biodiversity and ecosystem services) [Color figure can be viewed at wileyonlinelibrary.com]



measured by a landscape heterogeneity index (LHI) (Andersson et al. 2014), calculated as the first principal component (PC1) from a principal component analysis of the proportions of seminatural pastures and field borders in the nonoverlapping landscapes to represent a gradient from simple to complex landscapes (see Supplementary Materials, Landscape Heterogeneity Index). The aim is not to provide a universal LHI, but one that is meaningful given the type of agricultural regions and environmental responses that our study focuses on. Our focus is on landscapes that have a high proportion of agricultural land (>40%), with a percentage of the agricultural land covered by seminatural pastures and field borders below 50% (see Stjernman et al. (2019) for further details). In these regions, seminatural pastures and field edges are elements of landscape heterogeneity that are important for biodiversity and ecosystem services, as substantiated by extensive empirical findings.

Environmental Impact Indicators

Environmental impacts were evaluated for bird biodiversity, biological control in spring barley, and wild bee pollination in oilseed rape and seminatural habitats. We used ecological production functions for which predictive performances are grounded in a mechanistic representation of the processes behind the provision of ecosystem services, statistical calibration, and validation using empirical data. Here we briefly present these production functions while details are provided in the Supporting Materials (under Ecological modeling).

To evaluate the impacts on biodiversity, we downscaled land-use predictions from AgriPoliS under the different scenarios to predict the abundances of a set of 15 farmland bird species used by Swedish authorities to monitor the

fate of biodiversity in farmland. Abundances were summarized into a biodiversity index defined as the mean of predicted abundances of the included species on the log scale. As a biodiversity production function we used a statistical model from a study on the effects of agricultural intensification on farmland birds in the same regions. The predictive ability of the production function for farmland bird diversity was motivated by the selection of predictors based on expert knowledge using mechanistic understanding, the structure of the statistical model considering covariation between species, and the calibration and validation using bird data collected in a field study conducted in the GSS and GMB regions (Stjernman et al. 2019).

Biological pest control is provided by beneficial natural enemies such as predators, parasitoids, and pathogens (Ehler 1998), and it may benefit from increasing the availability of relatively undisturbed habitats in farmland (Holland et al. 2017). A high biological control potential may increase yields or allow less use of pesticides (Bengtsson 2015). Impacts on biological control by natural enemies was evaluated using a cereal aphid biological control model (Jonsson et al. 2014). The predictive ability of the production function for biological control was motivated by mechanistic understanding and validation based on data from a field experiment conducted in Sweden (Jonsson et al. 2014).

To determine the pollination potential in our landscapes, we used a model that estimates the abundance of the most important wild pollinator group (wild bees), based on the availability of floral resources and nesting sites (Häussler et al. 2017). The pollinator visitation rate in a pixel in a landscape depends on the floral quality and land cover of that pixel, the proximity to nest sites, and the total availability of food resources in the landscape. For each landscape, we used the average visitation rates per hectare in oilseed rape fields and pastures. We selected oilseed rape as the focal crop for pollination, because as a mass-flowering crop it has an effect on the reproduction of bees with consequences for population sizes later in the same year or even in the next year (Riedinger et al. 2014). The predictive ability of the production function for pollination was motivated by the mechanistic understanding using foraging theory.

Policy Scenarios

To evaluate the consequences of the 2013 reform, we continued the 2005–2014 CAP framework (i.e. based on the 2003 reform) to 2020 with its region- and farm-specific decoupled direct payments as the baseline scenario (CAP 2003) and compared it to the policy resulting from the 2013 reform (see Methods for modeled components) and simulated over the period 2015–2020 (CAP 2013).

To test the sensitivity of the impacts of the new policy to the rules defining the EFA obligation, we subsequently evaluated three hypothetical EFA scenarios. In one scenario, the EFA area obligation was increased to 15% (EFA15) to evaluate whether stricter conditions would benefit biodiversity conservation, given the criticism that the current area obligation is too low. In addition, since it is questioned whether the current weighting system captures the relative biodiversity values, we also simulated two hypothetical scenarios in which we eliminated the area weights, to test the efficacy of the weightings, EFA5 (no weights) and EFA15 (no weights) respectively.

Table 1 Regional Structural Change Relative to CAP 2003 Scenario in 2020

Region	Scenario	No. of farms (Δ% 2020)	Average farm size (Δ% 2020)	Average profit per farm (Δ% 2020)
GMB	CAP 2013	−2.8	3.1	0.0
	EFA15	−1.5	2.1	−0.4
	EFA5 (no weights)	−1.2	1.0	−0.7
	EFA15 (no weights)	−2.5	3.1	−2.1
GSS	CAP 2013	−19.9	24.7	−10.8
	EFA15	−21.9	27.8	−9.2
	EFA5 (no weights)	−20.7	25.8	−10.6
	EFA15 (no weights)	−21.7	27.8	−10.8

Note: Results for the CAP 2003 scenario in 2020 for GMB are: no. of farms 1,620, average farm size 97 ha, and profit per farm €38,622; for GSS: no. of farms 1,985, average farm size 97 ha, and profit per farm €54,193. In addition, the number of farms and average farm size differ from the data listed in table S1 in the Supporting Materials, because of simulated farm structural change to 2020.

Results

Impacts on Agricultural Development and Land Use

The 2013 reform (CAP 2013 scenario) speeds up structural change in both regions compared to a political status quo (CAP 2003 scenario), as farms become fewer and larger in both regions in 2020 (table 1). The effect is stronger in GSS compared to GMB, indicated by a larger decline in the number of farms and average farm profit. The main reason for this is the national equalization of direct payments (to €193/ha), rather than the EFA obligation. Equalization means that direct payments decrease only marginally in GMB (from €200/ha) but considerably in GSS (from €330/ha). Although the faster structural change in GSS permits average farm size to grow, the associated economies of scale are not sufficient to fully mitigate the negative impact of the lower payment on farm profits.

Each of the reform's three major components (equalization, voluntary coupled support to cattle and EFAs) has the potential to influence land use and hence the environment. Table 2 displays the reform's effects on land use including choices of EFA types on high and low productive land in both regions.

In GMB the CAP 2013 scenario resulted in a reduction in the area of fallow land and an increase in arable land used for grain and grass production for fodder on low productive land, which was mainly driven by the new coupled support boosting cattle numbers. As stated above, equalization of direct payments played a minor role in this region because of the marginal reduction in decoupled payments to the region. To meet the EFA obligation, farmers could count existing fallow land that was not profitable to farm in the CAP 2003 scenario (an area that also declined in CAP 2013 because of the coupled cattle payment). To complete their EFA obligation, the fallow land was supplemented with field margins and nitrogen-fixing crops on low productive land. These choices are attributable to the generous weighting of field margins (i.e., 1 ha field margins counts as 9 ha fallow), while nitrogen-fixing crops have productive value as they can be sold (table 2).

Table 2 Land Use (ha) in GMB and GSS by Soil Productivity and Scenario in 2020

Region	Scenario	Crops grown on HIGH productive arable land				Crops grown on LOW productive arable land				EFA types placed on HIGH productive land				EFA types placed on LOW productive land				
		Sugar beet		Oilseed rape	Barley	Oilseed rape		Grass silage	Ley	Pasture	Fallow land	Nitrogen-fixing crops	Catch crop	Field margins	Fallow land	Nitrogen-fixing crops	Catch crop	Field margins
		Wheat																
GMB	CAP 2003*	26,182	13,703	12,595	20,338	0	19,529	7,670	22,654	—	—	—	—	—	29,101	965	—	—
	CAP 2013	29,402	10,224	12,589	21,283	0	20,942	8,682	22,813	—	238	—	—	27	24,761	1,743	—	379
	EFA15	29,343	10,317	12,595	21,954	0	20,583	8,472	22,898	—	225	—	—	—	23,505	1,854	—	1,420
	EFA5 (no weights)	29,385	10,260	12,595	21,969	0	20,586	8,478	22,898	—	218	—	—	—	24,813	1,890	2,380	—
GSS	CAP 2003*	28,504	10,987	12,595	18,282	0	20,438	8,332	22,889	—	337	—	—	—	29,811	1,207	7,717	—
	CAP 2013	98,264	26,733	14,451	19,561	3,414	5,192	2,033	6,956	5	5,058	—	—	—	7,166	3,945	—	—
	EFA15	98,264	26,734	14,451	4,559	1,309	5,103	1,890	6,944	—	5,058	—	—	4	26,382	230	—	67
	EFA5 (no weights)	98,256	26,731	14,449	4,206	1,260	5,032	1,842	6,974	9	5,057	28	—	—	26,882	263	17	—
EFA15 (no weights)	EFA15 (no weights)	98,166	26,707	14,436	2,862	1,077	4,868	1,742	6,924	140	5,053	490	—	—	29,614	221	221	—

Note: *in the CAP 2003 scenario there is no EFA obligation however we show the land uses that would qualify as EFA.

An increase in the EFA obligation to 15% of the farm area (EFA15) resulted primarily in an increase in field margins on low productive land in GMB. These have a generous weight and hence allow farmers to meet the EFA obligation with small reductions in the area in crop production. When the weighting factors are considered, neither catch crops nor willow were chosen as EFA because of their low weighting factor (0.3) compared to fallow land (1.0), nitrogen-fixing crops (0.7), and field margins (i.e., 3.3 ha catch crops or willow counts only as 1 ha EFA). When catch crops are not weighted (the no-weight scenarios), they become relatively less costly to farmers than field margins. As a result the area of catch crops increased substantially on low productive land in GMB in the EFA5 (no weights) scenario, and even more when the obligation is increased from 5 to 15% in the EFA15 (no weights) scenario.

Under the reformed policy (CAP 2013) farmers in GSS significantly increased the fallow area on low productive land compared to the CAP 2003 scenario. However, this increase is primarily driven by the reduction in the decoupled payment rate, rather than the EFA obligation. In 2020 the equalized payment is 41% lower than the regional decoupled payment in 2014, thus crop production on a large area of low-productive land becomes unprofitable (since decoupled payments are tied to land they reduce the opportunity cost of using land as a production factor, and thereby indirectly promote more extensive production). However, the land is profitable to maintain as fallow in order to meet the cross-compliance conditions for collecting direct payments, as is intended by the policy. The higher weighting factor for field margins was not as important to farm-agents in GSS as in GMB, since the increase in fallow land could be counted as EFA, thus making the EFA obligation largely redundant (i.e., they would have increased the area in any case due to the reduction in payment rate). However, with the stricter obligation of 15% EFA, some area of low productive land is converted to field margins, to minimize the area taken out of the highly profitable intensive arable crop production (table 2, EFA15 scenario).

On removing the weights in the hypothetical EFA scenarios, catch crops were not chosen to the same extent in GSS as in GMB, because of the increase in fallow land resulting from the equalization of payments. This again indicates that the land use changes in this region are primarily driven by the equalization of payments, while the effect of the EFA obligation per se is marginal. Further, the 5% EFA obligation was largely met by many farm agents before the policy change thanks to the large area of nitrogen-fixing crops that are profitable to grow in this region, e.g. peas for human consumption (table 2, CAP 2003 scenario). This area remained constant over time on high productive land but was reduced and converted to fallow on low-quality land. The cattle payment played a smaller role in GSS than in GMB since crop production is the dominating activity in the region.

The small effect of the EFA obligation on agricultural structure is due to several watering-down effects. First, the EFA obligation applies at the farm level rather than being spatially targeted at the landscape scale. Therefore, the farm agents were found to be able to dynamically adjust their land holdings, by acquiring and allocating low productive (or marginal) land to meet the EFA obligation, rather than having to take high productive land out of production (table 2). Second, the equalization of payments drove an increase in the fallow area in GSS, which resulted in farm agents putting far more (low productive) arable land in the fallow area than needed to meet the EFA obligation, and consequently almost no high productive land was used for EFA

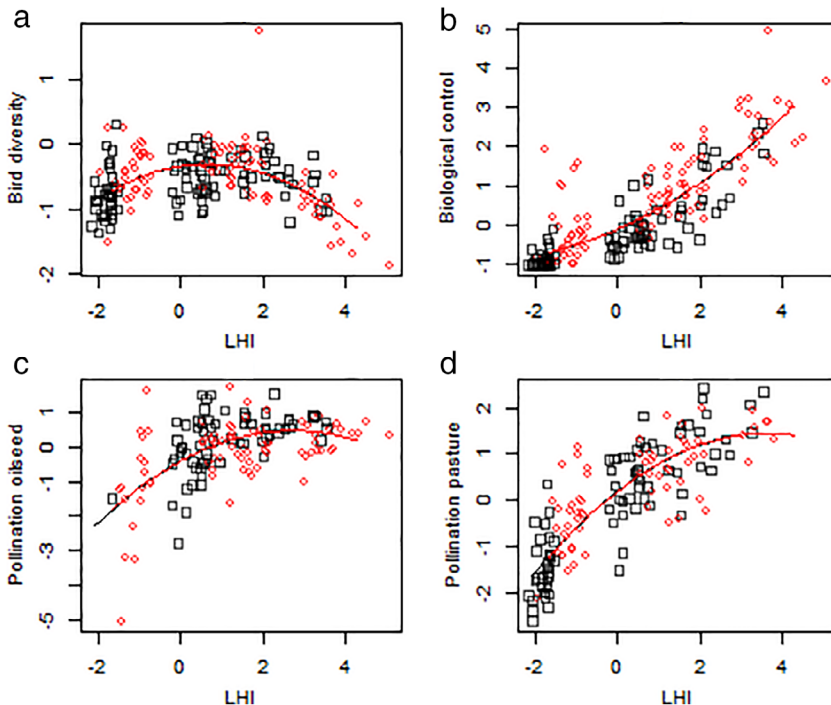
measures. Third, the weighting factors for field margins greatly reduced the need to take land out of production to meet the 5% obligation. Fourth, the low EFA obligation and the relatively large area of land uses qualifying as EFA prior to the reform acted in combination to minimize the potential impact of the EFA obligation on farm structural change and land-use patterns. This is especially true for the large existing areas of nitrogen-fixing crops in GSS and fallow land in GMB (table 2).

Consequently, farm agents were generally found to be able to continue to use their most productive land in crop production, thereby offsetting the higher costs that would arise if forced to take high productive land out of production to meet the EFA obligation.

Environmental Impacts

In order to test the effect of landscape heterogeneity on the current and simulated changes in the environmental indicators, 200 agricultural landscapes (blue dots in figure 2) were selected using criteria targeting an orthogonal design¹. Figure 3 shows that the predicted levels for bird diversity, biological control, and pollination obtained from the ecological production functions, vary as a result of landscape heterogeneity within the two regions (figure S1 Supporting Materials). Biological control from natural enemies and wild-bee pollination in oilseed rape fields and pastures is higher in landscapes with a higher LHI (figure 3).

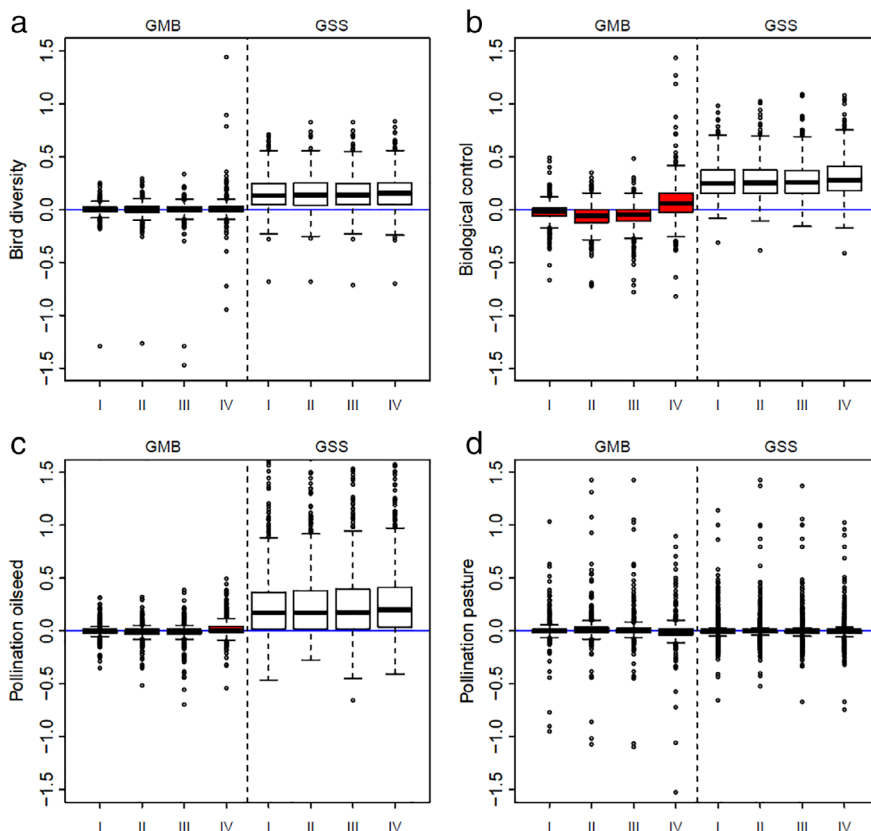
Figure 3 Importance of landscape heterogeneity in driving environmental variables in a sample of landscapes within each region (GMB red circles and GSS black squares). Variables are z-transformed, higher values indicate better outcomes. The effect of landscape heterogeneity on the current levels of biodiversity and ecosystem services in the baseline scenario was significantly different from zero for all indicators [Color figure can be viewed at wileyonlinelibrary.com]



For farmland bird diversity, predictions are higher for landscapes of intermediate complexity than for homogeneous landscapes, but predicted diversity is reduced also in landscapes with a very high landscape heterogeneity. The production function for bird biodiversity includes interactions between landscape heterogeneity and land use; although generally the estimates of interaction effects are quite low, they are mostly negative, suggesting that extensive and/or more diverse agricultural land use is less beneficial in heterogeneous landscapes compared to homogeneous ones. The other two ecosystem-service predictions are derived from models using the nonlinear processes linking landscape composition to the ecosystem services in the models, and that is why their predictions are able to capture a higher dependence on increasing landscape heterogeneity.

There is a small positive change in bird diversity in the GSS region when comparing the CAP 2013 scenario to the CAP 2003 scenario (zero line in figure 4). The effect on bird diversity was positive and significantly different from zero in the GSS region (p -value < 0.001 , likelihood ratio test), but not in the GMB region (p -value > 0.05 , likelihood ratio test). The difference in predictions from the two regions is mainly driven by the change in the area of fallow land according to table 2, which is predicted to increase on low productive

Figure 4 Impacts of the different policy scenarios I) CAP 2013, II) EFA 15, III) EFA 5 (no weights) and IV) EFA 15 (no weights) on biodiversity and ecosystem services, where the difference compared to the baseline is represented as the proportion of the z-transformed values observed in the baseline (CAP 2003) scenario, using the complete set of landscapes. Values higher than zero indicate better environmental outcomes than in the baseline (CAP 2003) [Color figure can be viewed at wileyonlinelibrary.com]



land in GSS but not in GMB. The proportion of extensive crops (including fallows) is, together with the even more important area of farmland and LHI, the main driver of bird biodiversity in the biodiversity production function, hence explaining the regional pattern. In addition, the effect of extensive crops is stronger in less heterogeneous landscapes (negative interaction between proportion of extensive crops and LHI in the bird model), further exacerbating the difference between the regions.

The effects of the scenarios on the potential for natural biological control of pests were strongly contingent on the particular region, with an effect significantly different from zero only in the GSS region (p-value <0.001 likelihood ratio test²). This effect depends on landscape heterogeneity. In the biological control model, the areas of pasture and noncropped land at various distances from cereal fields are the driving variables. Since GMB is pasture rich and has high landscape heterogeneity (see Figure S1 Supporting Materials), it had higher outset values for biological control than GSS. Thus, the changes in land-use brought about by the greening reform (CAP 2013 scenario), specifically the reduction in the area of fallow land in GMB on the one hand and the substantial increase in GSS on the other, lead to a very small reduction in biological control value in GMB but an increase in GSS (figure 4b). The hypothetical scenarios gave similar results, except for a small increase in the EFA15 (no weights) scenario in both regions. The area of fallow land is the highest in this scenario compared to the other hypothetical scenarios and the CAP 2003 scenario. However, in GMB, the area of fallow land is similar in EFA15 (no weights) and the CAP 2003 scenario, meaning that the increase in catch crops (undersown grass) partly drives the positive effect on biological control observed in EFA15 (no weights). It only partly drives the effect because the potential effects of catch crops on biocontrol are limited under intensive agricultural practices.

Pollination in oilseed rape increases with the CAP 2013 scenario in GSS but not in GMB. The change depends on the location of an EFA and the surrounding land use in a similar way as biological control, leading to somewhat comparable patterns. In GMB, because of the high landscape heterogeneity, the pollination services were relatively high before the reform. In addition, although the area of oilseed rape remained similar to the prereform area, resulting in no changes in the demand for oilseed rape pollination, the reduction in area of fallow land linked to the supply of habitat for pollinators, was not large enough to show any significant negative effect. The change in GSS can be linked to a lower demand for pollination services indicated by the reduction in area of oilseed rape on low productive land (see table 2), which results in a concentration of wild bees on remaining oilseed rape fields. There is also a substantial increase in supply of habitat linked to fallow land, boosting wild-bee abundance in the GSS region.

Pollination in pasture was not affected in any of the regions in any of the simulated scenarios (figure 4d). Again, the regional landscape aspect plays a major role, as does the area of semi-natural habitat, which remained similar between scenarios (table 2). The area of permanent pasture is large in GMB,

¹The 200 landscapes were selected from the total set using the D-optimal design criterion over the variables landscape heterogeneity and production region. The design ensured to keep the distribution of landscape heterogeneity similar over the two production regions.

²The likelihood ratio test is conducted on the predictions from the production function coupled to the AgriPoliS-generated land uses on the 200 selected landscapes.

providing enough habitats to support pollination services. This means that the reduction in the supply of area benefiting pollination services (fallow land) in combination with the high heterogeneity is not large enough to give any significant changes. In GSS, greater supply of habitats from fallow land compared to the baseline year in combination with low heterogeneity is expected to benefit pollination services. However, the effect was small because pasture does not cover a large area in GSS and because fallow land was not generally located in proximity to pasture.

Overall the simulated land-use changes resulting from the EFA obligation and their effects on the environmental indicators were very limited. Comparing the hypothetical EFA scenarios to the reformed policy (CAP 2013 scenario), the effects on environmental indicators remained similar with a small deviation for biological control in the EFA15 (no weights) scenario. Nevertheless, the mixed environmental impacts we simulated in the regions are not primarily a consequence of the greening EFA measure per se, but rather of the other reform elements. Coupled livestock support drove the results in the mixed livestock farming region, GMB, whereas in the specialized cropping region, GSS, it was the equalization of payments.

Discussion and Conclusions

Using an integrated ecological-economic modeling approach, we show that the 2013 CAP "greening" reform has little potential to improve biodiversity and ecosystem services on farms through the EFA measure. In particular, no effects emerged from the measure in the study region with high landscape heterogeneity (GMB), while only minimal effects emerged in the region characterized by specialized arable cropping and low landscape heterogeneity (GSS), i.e., the type of landscape where environmental measures are most needed.

Beyond landscape characteristics, the potential for the EFA measure to generate environmental benefits was watered down by the following particular flaws:

- I. *The broad range of designated EFA measures*, particularly the inclusion of productive land uses such as nitrogen-fixing (protein) crops. As a result, a majority of the farms in the study regions fulfilled the 5% criterion ipso facto, thereby avoiding any need to change their land use. This potential for passive compliance is corroborated by other studies finding that the aggregate impacts of the reform on land use in the EU are small (Gocht et al. 2017; Louhichi et al. 2018).
- II. *Lack of pertinent (environmental) management rules*. In our study regions it is permitted to repeatedly till uncropped field margins and treat them with herbicides, which greatly reduced the potential for these margins to benefit biodiversity according to our results, and would most certainly increase nutrient and greenhouse-gas emissions, which is consistent with criticisms of the EFA design (Pe'er et al. 2016).
- III. *The system of EFA weighting factors*. The generous weighting factor for field margins was not ecologically motivated for the reasons described in flaw II.
- IV. *The absence of spatial targeting of EFA measures*. Since the EFA obligation applies at the farm level, farmers minimized the cost of additional ecological-focus area, by locating these on their least productive land—a behavior that is confirmed in a workshop with real farmers Sahrbacher,

Hristov, and Brady (2017)—and hence not necessarily where it would generate the greatest environmental benefits. Normally, achieving environmental goals (cost-effectively) requires spatial targeting (Tscharnatke et al. 2005; Wätzold et al. 2016), which we show even applies to “greening” measures.

- V. *The ability for farms to adjust their land holdings.* Finally, any promised benefits of the EFA measure from a static perspective were all but eliminated in our dynamic simulations by the ability of farmers in the study regions to acquire (marginal or low productive) land on the endogenous land market as in reality. This resulted in almost complete concentration of additional EFA measures (i.e. those beyond the area satisfied ipso facto) on marginal land, thus allowing farmers to maintain intensity on their most productive land. A similar phenomenon has previously been experienced in the EU when farmers acquired remote plots of marginal land to comply with the set-aside obligation (Rygnestad and Fraser 1996). Therefore, we conclude that as long as farmers are free to locate EFA measures where they like, only the least productive land will, in the end, be affected, resulting in a complete dilution of the potential for improving biodiversity and ecosystem services.

Therefore, the design of the EFA measure, while marketed as a CAP innovation to benefit biodiversity, has resulted in little probability of achieving this goal in practice. Rather (as indicated by our results) it seems to have been focused on minimizing the costs of implementation for farmers instead of generating real environmental benefits, which is consistent with the view of political scientists (Alons 2017). Further, we demonstrated that stricter EFA obligations (e.g. increasing it from 5 to 15% of farms’ arable land), would still be ineffective, due to the identified flaws of the reform generally, and the lack of a landscape perspective (i.e. considering environmental heterogeneity) and spatial targeting particularly.

Our results and conclusions are subject to some limitations and qualifications. First, the areas and allocation of EFAs are simulated to the year 2020, rather than being observed. Second, the spatial allocation of land-use changes was done randomly, which means that the environmental impacts are likely to be underestimated compared to an optimal environmental allocation of farmers’ chosen measures. The motivation to not optimize the allocation from an environmental perspective was that this is not encouraged by the policy. Third, we used a limited set of environmental indicators, which consequently might not cover the full range of potential environmental impacts. Finally, we did not model potential positive feedbacks of EFA measures to farmers’ profits, through increased biological control of pests or crop pollination. However, it seems unrealistic to assume that farmers would do this to any large extent in the short run when it requires taking land out of production (Tilman et al. 2002). Further, as both pollination and biological control are generated by mobile organisms at the landscape scale, individual farmers share the benefits of creating habitat (a common-pool resource) with their neighbors. Resolving this “prisoner’s dilemma” would require collaboration among farmers (Cong et al. 2016).

In summary, the environmental performance of the CAP can only be improved if member states are allowed the flexibility to devise spatially targeted environmental measures that are complemented by the power to require evidence of environmental improvements as a basis for payments,

such as a form of result-based scheme (e.g. Sidemo-Holm, Smith, and Brady 2018). Such flexibility and power is available under Pillar II in relation to agri-environmental schemes, but is inconsistent with the need for a common policy design of Pillar I payments.

Overall, we believe the modeling approach applied here demonstrates considerable shortcomings of the CAP greening reform, particularly for common "greening" measures to generate environmental benefits commensurate with the magnitude of green direct payments.

Supplementary Material

Supplementary material is available online at *Applied Economic Perspectives and Policy* online.

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