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Assessment of the impact of agricultural support on crop diversity

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Abstract: This study examines the impact of agricultural support on crop diversity measured by a diversity index. Our results indicate that agricultural subsidies have a limited effect on agricultural biodiversity. By using unique farm-level data, we show that subsidies support the income of farmers rather than the agricultural biodiversity. The results are robust regarding the size, practice management and altitude of the agricultural holdings' operations and various measures of agricultural biodiversity. However, when interpreting the results, the limitations of biodiversity indices should be considered.

Keywords: biodiversity index; Czech Republic; panel data regression; subsidies

This study contributes to the debate about the effectiveness of agricultural policies in achieving the objectives of halting biodiversity loss by conducting an in-depth analysis of the farmland biodiversity response to agriculture subsidies. Moreover, this study reveals, for policy design, important information on whether the heterogeneity between agricultural producers in the type of farming, agricultural management practice, localisation, and size lead to different responses to policy measures.

Using unique farm-level data in the Czech Republic, we assess the impact of agricultural subsidies on the agricultural biodiversity proxied by the Simpson Index of Diversity (SID). In general, SID considers the relative abundance of various land use. Employing the panel data regression analysis, we conclude that

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subsidies have a negligible positive impact on the agricultural biodiversity. In other words, subsidies support the income of farmers rather than the agricultural biodiversity.

In many European countries, a decline in biodiversity, defined as the variability among living organisms, including genetic diversity within a species, between species, and ecosystems (United Nations 1992), is observable within both natural and agricultural areas. Numerous studies (Donald et al. 2001; Wretenberg et al. 2007; Stoate et al. 2009; Foley et al. 2011; Poláková et al. 2011; Batáry et al. 2015; Tilman et al. 2017; Brunetti et al. 2019; IPBEZ 2019) have identified several changes in farming systems over the last decades, especially the intensification, concentration, and specification, as the main drivers of the biological diversity loss. The values of the Common Farmland Bird Index (Eurostat 2022), formally adopted by the European Union (EU) as an indicator of structural changes in biodiversity in response to land-use changes, highlight, in particular, the farmland biodiversity decline in Lithuania, Belgium, the Netherlands, France, and the Czech Republic.

At the same time, agricultural biodiversity, which is defined as the variety and variability of animals, plants, and micro-organisms that are used directly or indirectly for food and agriculture (FAO 1999), represents a fundamental economic asset providing a flow of ecological services for agricultural producers and contributes to food security by improving the agricultural sector's resilience to climate change, environmental risks, and socio-economic shocks (European Commission 2021). Specifically, crop diversity, which represents the cultivation of a multitude of crops at the farm level that creates differentiations in the soil fauna, weeds, pests, and predators (Nastis et al. 2013), was recognised as natural insurance for risk-averse farmers (Baumgärtner and Quaas 2010) with positive impacts on the farm performance (Brunetti et al. 2019) including agricultural productivity improvements (Di Falco and Chavas 2006; Asrat et al. 2010).

Decisions regarding the degree of crop diversity depend on agro-ecological, economic, and political factors (Smale et al. 2003; Benin et al. 2004; Capitanio et al. 2016); among them, the Common Agricultural Policy (CAP) instruments play a significant role in the EU (Pe'er et al. 2022). Previously, Di Falco and Perrings (2005) analysed the impact of the CAP on crop diversity, measured by the Shannon Diversity Index (SDI) in South Italy. Based on the stochastic revenue function, their results pointed out that if financial support is concentrated on a few crops, farmers will specialise in these few crops, causing a reduction in crop diversity.

A similar result was obtained by Nastis et al. (2013), who employed a stochastic revenue function on farm-level data of organic crop farms in Greece to evaluate the impact of organic farming financial support on crop diversity measured by the SDI. According to their results, the support can reduce agrobiodiversity if only a few crops are supported, although the organic cultivation method enhances biodiversity. Both studies highlighted the potential risk of a trade-off between financial farm support and crop selection in managing the production risk, meaning that policies aimed at supporting the agricultural producers' income can lead to a delink in the crop diversity strategy from the management of the revenue risk. Organic farming support is a part of agri-environment schemes (AES) that have become the leading primary CAP tool to mitigate or reverse the consequent biodiversity loss on European farmland (Batáry et al. 2015). Numerous studies have investigated the effectiveness of the financial incentives to adopt environmentally friendly management practices provided under the AES with a biodiversity target (Kleijn and Sutherland 2003; Overmars et al. 2013; Batáry et al. 2015; Walker et al. 2018; Tyllianakis and Martin-Ortega 2021) with the conclusion that the agri-environmental measures have a positive impact of on the farmland biodiversity. However, the limited success in reversing the biodiversity loss (Pe'er et al. 2022) due to barriers to the farmers' adoption of these voluntary schemes (Tyllianakis and Martin-Ortega 2021) was identified at the same time.

During the CAP reforms, AES was complemented by other measures focused on environmentally friendly practices facing biodiversity loss; among these, the most notable are Cross-compliance and Greening measures in Pillar 1 (Matthews 2013). While the former conditions the payment entitlements from Pillar 1 on maintaining agricultural land in a Good Environmental and Agricultural Condition (GAEC) respecting the relevant statutory management requirements (Brady et al. 2019), the latter directly supports biodiversity through crop diversification, maintaining permanent grassland and creating ecologically focused areas (Alons 2017). In other words, these measures incentivise farmers to produce environmental public goods for society in return for receiving direct payments (Gocht et al. 2017). Several studies have attempted to analyse the effects of these measures (Mahy et al. 2015; Gocht et al. 2017; Pe'er et al. 2017; Hristov et al. 2020).

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Although employing different methods [non-parametric simulation based on peer behaviour (Mahy et al. 2015); the spatial, partial equilibrium model (Gocht et al. 2017); expert evaluation (Pe'er et al. 2017); the dynamic agent-based model with ecosystem-service production functions (Hristov et al. 2020) and biodiversity measurements: SDI (Mahy et al. 2015); biodiversity-friendly farming practices index (Gocht et al. 2017); farmland bird index (Hristov et al. 2020)], these studies concluded on the positive, albeit the generally small, impact of these measures on the biodiversity and, as a result, called for improvements to CAP that would improve its eco-efficiency and cost-effectiveness. CAP post-2023 proposes a new Green Architecture around area-related instruments to address the effectiveness weaknesses: enhanced conditionality and eco-schemes in Pillar 1 and agri-environmental-climate measures in Pillar 2 (Pe'er et al. 2022).

The following section provides the study's methodological framework and presents the data. The results section reports the relationship between the diversity indices and subsidies and discusses the key findings. The last section concludes with a summary of the key results and policy implications.

MATERIAL AND METHODS

Farm-level data allowing to measure biodiversity

Biodiversity measurement. Biodiversity is a complex concept whose empirical analysis is limited by data availability and is affected by choosing the appropriate indicator. Because this study is based on farm-level data, three different measures of biodiversity, which can be calculated from the data obtained from the Farm Accountancy Data Network (FADN), are employed in the empirical analysis. In particular, the FADN database allows us to analyse land use and crop diversity. Land-use diversity represents the richness, and the evenness of the agricultural land uses in a given farm. Under the assumption that a greater land-use diversity increases the number of different habitats (Weibull et al. 2003; Bennett et al. 2006; Overmars et al. 2013), the land-use diversity measurement approximates the diversity produced by farms well and can provide us with information for assessing the biodiversity production of different types of agricultural producers. Alternatively, this assessment can be based on crop diversity, which represents the variety and variability of the crops planted on a given farm, where previous studies (Josefsson et al. 2017; Redlich et al. 2018; Beillouin et al. 2021) found the crop diversity's positive impact on the biodiversity.

In general, the Shannon Diversity Index and the Simpson Index of Diversity (*SID*) are traditional diversity measurements that reflect diversity in terms of richness and evenness. In focus on land-use diversity, richness represents the number of different land-use activities, and evenness refers to the relative abundance of different land-use. The Shannon diversity index has been applied in several biodiversity and land-use studies (Brady et al. 2009; Nastis et al. 2013; Sipiläinen and Huhtala 2013; Mahy et al. 2015). However, this index is sensitive to rare land-use categories. Thus, this study prioritises the Simpson Index of Diversity (more precisely, the Gini-Simpson Index of Diversity, see Daly et al. 2018) that was used, e.g. by Mofya-Mukuka and Hichaambwa (2018) and Jarafi et al. (2022).

According to Jarafi et al. (2022), the *SID* is calculated as follows [Equation (1)]:

$$SID = 1 - \sum_{l=1}^{L} p_l^2 \tag{1}$$

where: L – set of different land uses $l \in L$; p_l – share of total land area covered by the l^{th} land-use $p_l = \frac{a_l}{\sum_{l=1}^{L} a_l}$, where a_l – the area of the l^{th} land use.

In the case of mono-land-use, *SID* equals zero, indicating no diversity. The *SID* value increases with a higher number of land-uses and reaches a value close to one if the land-use diversification is complete. The development of the index is non-linear. That is, the increment of this index becomes lower with an increase in the number of land-use activities. Assume a farm with 100 ha of agricultural land, which is equally divided between two land use activities, that is L = 2 and $a1 = a2$, *SID* = 0.50. The additional land use activity under the assumption that $a1 = a2 = a3$ increases this index to 0.67. If this farm has eight land-use activities that are equally distributed on the agricultural land, *SID* = 0.88 and the increase to L = 9 leads to an increase in *SID* to 0.89. If L > 20, then the changes in *SID* reflect more changes in the evenness rather than in the richness. If L = 2, $a1$ = 99, and $a2$ = 1, then *SID* = 0.02. Increasing $a2$ to 2 together with decreasing $a1$ to 98 changes *SID* to 0.04. That is, the change is 0.02 while increasing $a2$ from 49 to 50 combined with decreasing $a1$ from 51 to 50 changes the *SID* by 0.0002.

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The FADN data allows us to calculate two variants of *SID*. The first (*SID* land-use) is based on nine categories of land-use: the area of cereals (SE035), the area of other field crops (SE041), the area of vegetables and flowers (SE046), vineyards (SE050), orchards (SE055), the area of other permanent crops (SE065), the area of forage crops (SE071), the area out of production (SE074), and woodland area (SE075). The second (*SID* field crops) is specified for field crops and covers the areas of rye, oats, barley, wheat, maise, peas, rape, poppies, mustard, flax, sugar beets, potatoes, and other field crops.

Moreover, according to Ofori-Bah and Asafu-Adjave (2011), the third diversity measure is constructed using information about the agricultural output production and employing the reciprocal of the Herfindahl Index. This Diversity Index (*DIV*) is targeted to measure the crop diversity in this study and is calculated as follows [Equation (2)]:

$$DIV = \frac{1}{\sum_{q=1}^{Q} Y_q^2} \tag{2}$$

where: Q – set of crop species $q \in Q$; Y_q – fraction of the farmer's output generated from crop q; DIV ranges between 1 and infinity; higher values correspond with highly diverse farms.

This index increases linearly with an increase in Q, but non-linearly with a change in the evenness.

Based on the FADN data, 11 crop output categories are employed in this index: cereals (SE140), protein crops (SE145), potatoes (SE150), sugar beets (SE155), oil-seed crops (SE160), industrial crops (SE165), vegetables and flowers (SE170), fruit (SE175), wine and grapes (SE185), forage crops (SE195), and other crops output (SE200).

The preliminary analysis of these diversity indices employs the standard statistical procedure of a correlation analysis of these indices and the subsidy payments targeted to biodiversity. The current Greening measures in Pillar 1 and the Agri-Environment-Climate Measures, subsidies for organic farming, and payments linked to Natura 2000 and the Water Framework Directive in Pillar 2 are recognised as the most relevant measures to support biodiversity (European Commission 2020). These subsidies are accounted for under the environmental subsidies (SE621) and decoupled payment (SE630) in the FADN data. Furthermore, the FADN dataset allows us also to investigate the effect of the subsidies for farmers in disadvantaged areas (SE622), on other rural development payments (SE623), on the total subsidies on crops (SE610), and other subsidies (calculated as the difference between the total subsidies (SE605) and the subsidies listed above).

Furthermore, the heterogeneity in these diversity indices is investigated by considering different types of farming [field crops and mixed – the Community typology defines eight main types of farming according to the contributions of the different lines of production to the total standard output. These types are field crops, horticulture, wine, other permanent crops, milk, other grazing livestock, granivores, and mixed (European Commission 2022)], various agricultural management practices (organic and conventional), the localisation of a farm at various altitudes, and the farm's economic size.

Random effect model with Mundlak's extension as the preferred one. The relationships between the subsidies and diversity indices are analysed using panel data regression analysis for a more in-depth investigation of the agricultural producers' response to the policy measures . Specifically, a random effects model using Mundlak's (1978) adjustment adding group-means for each time-varying explanatory variable with the biodiversity index (SID_{it} or DIV_{it}, where subscripts i, with $I = 1, 2, \ldots, I$, and t, with $t = 1, \ldots, T$, refer to a certain farm and year) as a dependent variable and the subsidies ($X_{j,it}$) in log-form as independent variables is specified as follows [Equation (3)]:

$$Y_{it} = \left(\alpha + \nu_i\right) + \sum_{j=1}^{J} \beta_j X_{j,it} + \sum_{k=1}^{K} \beta_k Z_{k,it} + \sum_{k=1}^{K} \beta_l \overline{Z_{k,i}} + \sum_{j=1}^{J} \beta_m \overline{X_{j,i}} + \varepsilon_{it} \tag{3}$$

where: Y – biodiversity index; X_j – j^{th} type of subsidy; Z_k – k^{th} control variable; $\overline{Z_{k,i}}$ and $\overline{X_{j,i}}$ – group means; ν_i – random heterogeneity specific to the i^{th} farm, which is assumed to be strictly uncorrelated with the regressors: $E(\nu_i|\boldsymbol{X}) = 0$ and $E(\nu_i|\boldsymbol{Z}) = 0$; α, $\boldsymbol{\beta}$ – parameters to be estimated (bold – vectors); $\varepsilon_{it} \sim N\left(0, \sigma^2_{\varepsilon_{it}}\right)$ – idiosyncratic error term (Greene 2008).

We estimate the linear effect between the subsidies and land-use diversity, which we base on the fact that the nonlinearity of the diversity index does not automatically imply the non-linearity of the relationship between the subsidies and the index. Moreover, our dataset suggests a relatively narrow interval, where most *SID* index values are. Thus, we avoid extreme

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values, where other than linear relationships might be relevant.

As an alternative approach, we employed the instrumental variable method. However, our data allow us to use only limited instruments, such as the farmer's income, which turns out to be very weak. Therefore, we do not report these results. Alternatively, we considered the fixed effect model; nevertheless, the random effect with Mundlak's extension better captures the nature of the dataset since it provides both between and within parameter estimates. In particular, the subgroup farmer's means can deviate slightly from the big group mean, but not by an arbitrary amount, which the fixed effect method does not consider.

Specifically, this study investigates the effect of the total subsidies (SE605; *Tot. subsidies*$_{it}$), decoupled payments (SE630; *Direct payments*$_{it}$), environmental subsidies (SE621; ES_{it}), subsidies for farmers in disadvantaged areas (SE622; *Disadvantage areas*$_{it}$), other rural development payments (SE623; *Other rur. dev. subsidies*), total subsidies on the crops (SE610; *Tot. subsidies on crop*$_{it}$), and other subsidies (*Other subs.*$_{it}$). Furthermore, the empirical model specification includes several control variables to mitigate the omitted variable bias (similar to Capitanio et al. 2016). In particular, the following agro-ecological and economic variables are used as control variables: dummy variable for organic farming ($D_{OF,\,it} = 1$ if the farm practices organic farming management and $D_{OF,\,it} = 0$ otherwise), dummy variable for the farm type ($D_{MF,\,it} = 1$ if the farm practices both – plant and animal production and $D_{MF,\,it} = 0$ otherwise), dummy variable for the CAP programming period ($D_{NP,\,it} = 1$ for 2014–2020 and $D_{NP,\,it} = 0$ otherwise), dummy variables for the location ($D_{less300,\,it} = 1$ if the altitude is less than 300 m and $D_{less300,\,it} = 0$ otherwise; $D_{300–600,\,it} = 1$ if the altitude is 300–600 m and $D_{300–600,\,it} = 0$ otherwise; and $D_{more600,\,it} = 1$ if the altitude is more than 600 m and $D_{more600,\,it} = 0$ otherwise), dummy variables for the economic size ($D_{small,\,it} = 1$ represents farms with an economic size less/equal than/to 50 000 EUR and $D_{small,\,it} = 0$ otherwise; $D_{medium,\,it} = 1$ if the economic size is 50 001–500 000 EUR and $D_{medium,\,it} = 0$ otherwise; $D_{large,\,it} = 1$ if the economic size is 500 001–1 000 000 EUR and $D_{large,\,it} = 0$ otherwise; $D_{very\_large,\,it} = 1$ if the economic size is more than 1 000 000 EUR and $D_{very\_large,\,it} = 0$ otherwise), labour productivity (the ratio between the farm net value added and the labour; *Labour productivity*$_{it}$) in log-form, cropping intensity (the ratio of the arable land to the total utilised agriculture area; *Crop intensity*$_{it}$) in log-form, and fertiliser intensity (purchased fertilisers to the total specific costs ratio; *Fertiliser intensity*$_{it}$) in log-form. Categories of economic size are defined according to the European Commission's (2022) classification and FADN-CZ aggregation (Institute of Agricultural Economics and Information 2019).

The random effects model is estimated by the generalised least squares (GLS) estimator (for more details, see Greene 2008). All the estimation procedures and tests are performed in the software STATA 17.0.

Focus on the Czech Republic with its unique farm size. This study focuses on the Czech Republic, where agriculture is the most dominant land use, accounting for 53% of the total Czech land area. While 25% of the agricultural land is covered by permanent grassland, arable land represents 70% of the agricultural land in the Czech Republic (Czech Office for Surveying, Mapping and Cadastre 2022). However, the structure of the agricultural land has shown a slight shift from arable land to permanent grassland since 2000, according to the Czech Office for Surveying, Mapping and Cadastre (2022) (the share of arable land in agricultural land was 72% and permanent grassland was 23% in 2000). According to the Ministry of Agriculture of the Czech Republic (2002, 2022), the cultivation of agricultural land under organic management practices has become more popular since 2001, as the area under organic farming has increased from 5% in 2001 to 16% in 2021. Despite these changes, the Farmland Bird Index, which is Eurostat's official published measure of biodiversity, has declined in the Czech Republic and has been below the EU average over the last decade, see Figure 1.

Two specific features can characterise Czech agriculture – a significant share of land is farmed by large agricultural enterprises owned by legal entities, and a large share of entities farm on leased land. Although family farms account for 85% of all agricultural holdings, they manage only about 30% of the utilised agricultural area. This is reflected in their average hectare area, which was 42 ha per natural persons' farm in 2020, while the average size of the legal entities was 574 ha. Unlike legal entities, which owned only 21% of the agricultural area they managed, natural persons owned 48% of agricultural land (Czech Statistical Office 2020). According to the Ministry of the Environment (2016), the high proportion of agricultural land in the extended lease significantly limits the willingness for long-term and sustainable agricultural land management. One of the consequences is the increasing focus on large-scale, highly mechanised crop production connected with the excessive use of nitrogen and phosphate fer-

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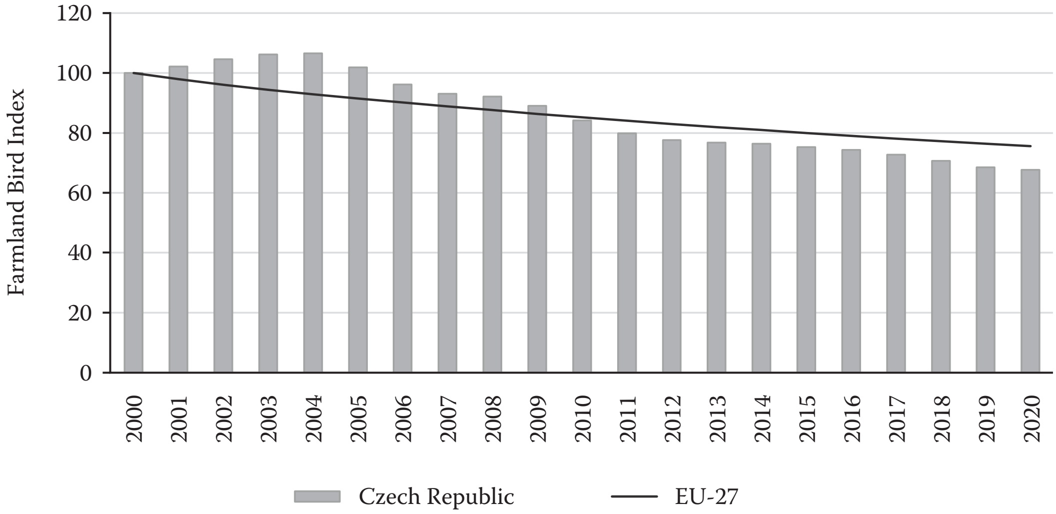

Figure 1. Farmland Bird Index (2000 = 100)

Source: Eurostat 2022

tilisers (fertiliser consumption per ha was 1.45 times higher in 2021 than in 2000, see Czech Statistical Office (2022a). This intensification and landscape homogenisation are crucial factors shaping Czech farmland biodiversity (Šálek et al. 2021).

According to the Czech Statistical Office (2022), the two most important types of farming in the Czech Republic: mixed farms, that cultivate the most significant part of the Czech agricultural land (35%) and field crop farms, which represent the largest share of the Czech agricultural holdings (34%). While field crop farms with an average area of 125 ha per farm (468 ha in the case of legal entities) are the larger group, mixed farms can be characterised by their larger size with an average area of 298 ha per farm (1 368 ha for holdings of legal persons). Both groups are targeted in this study.

The data employed in this study are obtained from the Farm Accountancy Data Network (FADN) database, which provides unique harmonised microeconomic data (physical and financial data) of agricultural holdings. The drawn sample contains 10 327 observations of 1 796 field crops (56% of observations) and mixed crops and livestock (44%) farms according to the FADN farm typology from 2008–2020. The structure of the dataset is presented in the Electronic Supplementary Material (ESM), Table S1. The sample farms cultivate 17% of the total area of agricultural land in the Czech Republic (Czech Statistical Office 2022b) and produce 18% of the total agricultural output and 19% of the crop output in the Czech Republic on average in the analysed period (Czech Statistical Office 2022c).

RESULTS AND DISCUSSION

Subsidies have zero impact on the agricultural biodiversity. Table S2 summarises the results of the calculation of the diversity indices. The diversity index averages 0.509 for land-use, 0.630 for field crops, and 2.319 for crop outputs. Analysing the sample means, all these indices increased between 2008 and 2020. However, the more considerable growth of land-use diversity and crop output diversity is observable in the study period compared to the field crop diversity. The average land-use diversity increased from 0.472 in 2008 to 0.529 in 2020, and the average field crop diversity changed from 0.633 at the beginning of the study period to 0.648 at the end. The crop-output diversity increased from 2.201 in 2008 to 2.401 in 2020. The panel regression also reveals the positive trend of land use and crop-output diversity with a 1% level of statistical significance.

Table S3 extends the description of the diversity indices considering the observed heterogeneity of the analysed farms. A detailed statistical description of the diversity indices in the analysed types of farming is presented in the ESM, Table S4. Figure S1 in the ESM shows a graphical representation of the development of the diversity indices concerning the type of farm. Table S5 adds the results of the statistical tests of the differences in these indices in the groups generated by the observed heterogeneity. Summing up these results, we can conclude that the diversity is lower in the smaller farms, contrary to our expectations. In the case of field crop farms, the lowest values of both Simpson diver-

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sity indices are revealed in the category of organic and conventional small farms with altitudes under 300 m. The small organic farms with altitudes under 300 m also have the lowest crop-output diversity value. However, in the case of conventional farming, the lowest crop diversity value occurs in the group of small farms with altitudes over 600 m. The very large conventional farms with an altitude between 300 and 600 m have the highest means of field-crops diversity and output diversity in the case of field crops farming. However, the highest land-use diversity value is revealed in conventional medium farms with altitudes over 600 m. Also, in organic field crop farming, the diversity increases with the size in general.

A similar relationship between the size and diversity is revealed in the case of mixed farming, where the highest means of the diversity indices are in the category of very large farms but with different altitudes – 300–600 m in the case of the land-use diversity in organic/conventional farms and crop-output diversity in organic farms, over 600 m in the case of field-crops and crop-output diversity in conventional farms, and under 300 m in the case of field-crop diversity in farms with organic management practice. Contrarily, the lowest means of field-crop diversity and crop-output diversity are revealed in small farms with altitudes under 300 m in the case of conventional management practice and with altitudes over 600 m in the case of organic farms.

The study period is characterised by a significant increase in the volume of subsidy payments, see Figure 2. Figure S2 in the ESM adds the development of the Agri-Envi-Climate Measures, subsidies for organic farming, and NATURA 2000 payments. The average total subsidies (SE605), in which, on average, 51% are decoupled payments, increased from 200.6 thousand EUR in 2008 to 347.7 thousand EUR in 2020 per farm. The environmental subsidies (SE621) that accounted for 7% of the total subsidies on average increased from 20.8 thousand EUR in 2008 to 28.2 thousand EUR per farm on average in 2020. All the amounts are in nominal values.

The growth of the subsidy payments and diversity indices is reflected in their correlation. Table S6 shows a positive correlation between the different types of subsidies and the diversity indices in the study period. The negative, however weak, correlation is revealed only in the case of subsidies for organic farming. The lowest strength of the diversity-subsidy relationship is estimated for NATURA 2000 payments and other rural development subsidies (SE623). A stronger relationship is revealed between the diversity indices and the Agri-Environment-Climate Measures as a part of the Environmental Payments and Greening Measures as a part of the decoupled payments.

Table S7 shows our main results about the impact of the subsidies on the Simpson Index of Diversity (dependent variable) in its land use version using the random effect model with Mundlak's (1978) adjustment (for results for field crops and *DIV*, see ESM Tables S8 and S9).

In total, we selected five categories regarding used variables. Model 1 in the second column shows the

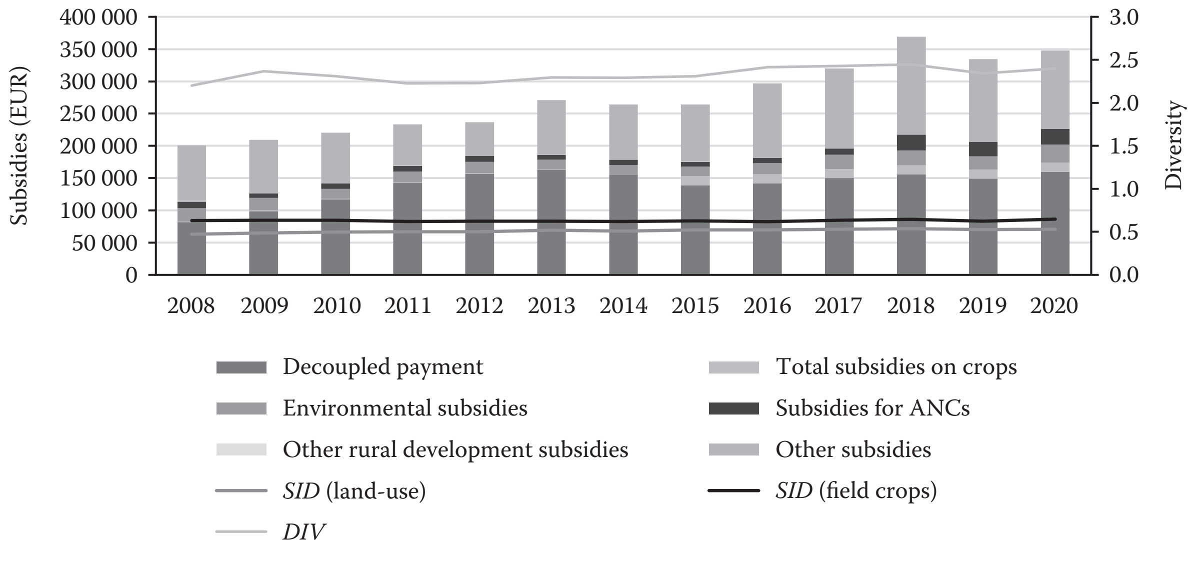

Figure 2. Development of diversity indices and the subsidies (in EUR)

SID – Simpson Index of Diversity; *DIV* – Diversity Index; ANC – Areas of natural or other specific constraints
Source: FADN and Eurostat (2023)

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total subsidies, cropping intensity, labour productivity, fertiliser intensity, and its group means. Given the level-log regression, we interpreted the results in the following way: Increasing the total subsidies by 10% increases the *SID* value by 0.004 with a 1% statistical significance.

Although the result is statistically significant, the economic significance is very low – almost zero. In other words, it shows that total subsidies do not play a crucial role in agricultural biodiversity. Interestingly, when we consider the heterogeneity of the farmers (Model 2 – third column), the coefficient for the total subsidies is even lower. This means that part of the impact of the subsidies is explained by the heterogeneity of the farmers. However, Model 2 shows that the total subsidies going to the organic or mixed farmer have no significant impact on the *SID* value. On the other hand, the altitude and size of the farm have a statistically significant effect. For example, *SID* is higher by 0.003 for the medium-sized farmer, who operates between 300–600 m altitude, than for the very large farmer operating up to 300 m – again, it is almost a zero effect.

Thus, looking at the subsidies at a granular level is interesting, which shows Model 3 in the fourth column. Essentially, the interpretation is the same as in Model 1. Considering the agri-environmental subsidies (row ES, Model 3), we can see a zero impact on *SID* or a shallow effect considering the group mean given by Mundlak's extension (row ES_gm, Model 3). The same interpretation holds for the decoupled payments, other rural development subsidies, subsidies for farming in areas facing natural or other specific constraints (ANCs), and the total subsidies on crops or other subsidies.

When adding the heterogeneity of the farmers (Model 4), we report similar findings – almost a zero effect. Furthermore, the impact of subsidies on *SID* is even lower. Finally, we were interested in farmers operating in the protected area of NATURA 2000 – the last column, Model 5. Here, we do not find any effect of the subsidies on *SID*. To a certain extent, it is a logical result since these areas were put in place between 2004–2005; thus, farmers had no impact on setting up these areas.

To sum up, all the models are consistent with the fact that the impact of subsidies, either the total or taken individually on *SID*, is almost zero. Additionally, all the models show that being a small or medium farmer means a lower impact of the subsidies on *SID* rather than being very large. This finding might be related to the current legislation that there cannot be a block of an individual crop larger than 30 ha or that small or medium farms are mainly family-owned with a different attitude to the landscape.

Limitations of *SID*. Given the multidimensional property of agricultural biodiversity, it is difficult to quantify it by one index simply. Therefore, no consensus exists about which indices are more appropriate and informative (Morris et al. 2014). We prioritise the Simpson Index of Diversity (more precisely, the Gini-Simpson Index of Diversity, see Daly et al. 2018) due to its feasibility of measuring the richness and evenness of the land cover, which is not sensitive to rare land-use categories. Significantly, most agri-environmental measures (bio belts or hedgerows) are typically based on the area of land, which is rare relative to the farmer's crop.

The mean of the Simpson Index of Diversity in the Czech Republic is 0.509, with a standard deviation equal to 0.137. To compare the mean value with the most recent data from other countries, Figure 3 shows *SID* by NUTS 2 in Portugal, Spain, France, Italy, and Greece. *SID* varies between 0.2 in Southwest Portugal and 0.89 in the East of Paris. Interestingly, the region of South Tirol in Italy reaches the value of 0.35. Thus, the Czech *SID* is around the average of the used countries.

As Morris et al. (2014) emphasised when considering complex interactions, choosing the right biodiversity index can profoundly alter the interpretation of the results. Nagendra (2002) offers a hypothetical example of two communities containing 100 000 individuals, one with six species and the other with 91. The Shannon index suggests that the second community has higher diversity, whereas the Simpson index indicates the opposite results. This divergence is explained by Peet (1974), who claims that the Shannon diversity index strongly responds to rare species, while the Simpson index strongly considers the proportional abundance of the most common species. To conclude, regarding our dataset, *SID* should not overestimate the agricultural biodiversity.

Interestingly, according to our results for the Czech farmers, *SID* increases with size in general. The reason for this phenomenon partially comes from the definition of *SID*. Naturally, the land use diversity increases with the size of the agricultural holdings. Moreover, it is given by the legislative (in the Czech Republic, a farmer cannot have more than 30 ha of one crop in one block of land due to the risk of erosion). Therefore, *SID* prefers larger agricultural holdings, even though the small farm with grasslands may have a similar level of agricul-

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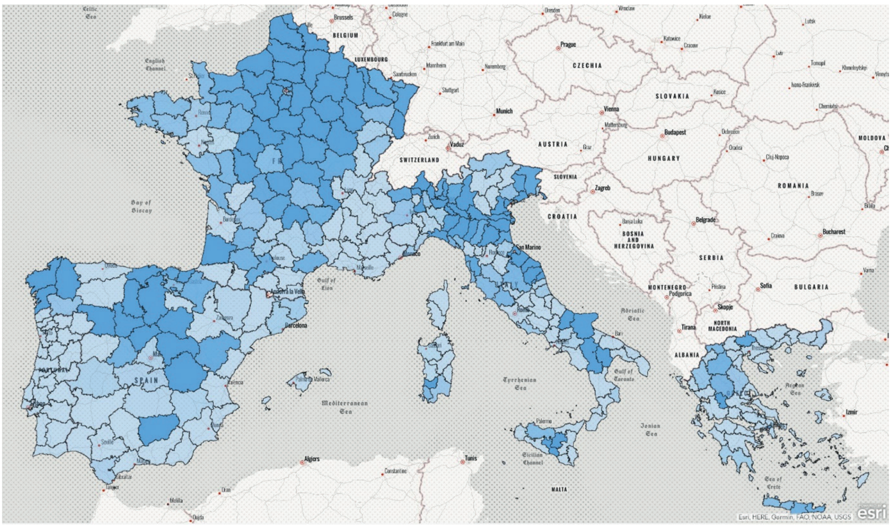

Figure 3. The north-east part of France indicates a high level of *SID*

The darker the colour, the higher the *SID* (Simpson Index of Diversity); for example, regions around Paris indicate *SID* > 0.7, whereas the North Italian region of South Tirol reaches the value of 0.35.
Source: Climate Resilience of Agricultural Systems 2020

tural biodiversity thanks to various species of flowers. To sum up, there is a need for the careful interpretation of *SID* when delivering the results.

Our results indicate a very small but significantly positive impact of agri-environmental measures on *SID* when considering Czech agricultural holdings. This aligns with the current literature (Mahy et al. 2015; Gocht et al. 2017; Pe'er et al. 2017; Hristov et al. 2020) aimed at other countries. The results could be interpreted as agri-environmental subsidies support farmers' income rather than agricultural biodiversity. Nevertheless, supporting farmers' income was one of the main goals of standard agricultural policy in 2014–2020. In this respect, the new CAP, which requires to aim higher about the environment, addresses these weaknesses by reallocating more payments to Eco-schemes and Agri-environmental & climate measures. Furthermore, the new CAP introduces an enhanced conditionality for these payments. However, it is up to each member state to put these conditions in place (Pe'er et al. 2017).

In light of our results, the selected principles for effective biodiversity protection that were highlighted by Pe'er et al. (2022): *i*) increasing the non-productive features (seminatural areas, bio belts, hedgerows) by requiring a minimum share of a farmer's land; *ii*) prioritising measures supporting crop diversity; *iii*) financial support enhancing collaboration with farmers regarding biodiversity targets; *iv*) combination of result-based and action-oriented payments indicate a high relevance for increasing agricultural biodiversity. However, the effectiveness of these measures is the subject of further research.

CONCLUSION

This study enriches the current stream of literature about the effectiveness of agricultural subsidies concerning agricultural biodiversity. We show that the size, altitude, and management practice play a minor role in the impact of subsidies on biodiversity. Importantly, we use unique farm-level data from the FADN database for the Czech Republic, which is not publicly available. This allows us to estimate the results robustly.

Agricultural holdings in the Czech Republic are one of the largest in the EU. As Swain (1999) puts it, after 1989, the cooperative form of former socialist agricultural holdings was more resilient, which might be one of the reasons for the largest farms on average in the EU. This is a crucial feature because determining the factors which affect the number of agricultural entities and the farm size on the agricultural land is very important for efficiently formulating the environmental policy and agricultural consulting for sustainable land management (Janovska et al. 2017).

In light of our results, increasing the number of subsidies might not positively influence the land-use diversity or biodiversity. Thus, measures specifically aiming at land use changes, such as increasing the non-productive features (seminatural areas, bio belts, hedgerows)

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by requiring a minimum share of the farmer's land, bio belts may play a more significant role in this respect. Other biodiversity-supportive measures can be prioritising efforts supporting crop diversity, financial support enhancing collaboration of farmers regarding biodiversity targets and a combination of result-based and action-oriented payments.

When interpreting our results, we need to consider the limitation of the Simpson Index of Diversity. *SID* is computed based on the area of land use. Therefore, it can omit other important determinants of agricultural biodiversity, such as fauna diversity. *SID* implicitly assumes that a higher diversity of land use results in a higher overall agricultural biodiversity (Weibull et al. 2003; Bennett et al. 2006; Overmars et al. 2013). Thus, comparing agricultural holdings in the same area might lead to different *SID* values, while the actual agricultural biodiversity does not need to vary much. Further research should consider the limitations of using *SID*. For example, using more granular data and field block-level data as a unit of interest.

Disclaimer. Data are subject to changes as a process of continuous improvement. Neither the European Union institutions and bodies nor any person acting on their behalf may be held responsible for the use which may be made of the information contained therein.

Data concerning the accounting year 2020 are considered preliminary as they are displayed as sent by Member States after national validation but without being fully validated by the Commission services. The Commission also wants to emphasise the use of Standard Outputs 2013 for the most recent accounting years. Updated figures using Standard Output Coefficients 2017 will be provided as soon as possible.

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