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Do Voluntary Commons Associations Deliver Sustainable Grazing Outcomes? An Empirical Study of England

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Abstract In 1965, the Commons Registration Act came into force in England and Wales. The Act led to the removal of the capacity of commoners to regulate the intensity of grazing via traditional legal means. From this policy shock a number of voluntary commons associations were formed. These voluntary groups relied on their members to agree upon how the commons should be managed. Using two-stage least squares regression analysis we find that commons governed by these associations are much more likely to produce sustainable grazing outcomes. These results are robust to the existence of a variety of controls, including overlapping institutional frameworks. Importantly, they highlight the ability of voluntary environmental organisations to deliver sustainable environmental outcomes.

Keywords Commons · Environmental governance · Voluntary agreements · Non-state institutions

1 Introduction

Some of England's most ecologically valuable natural environments are situated within common lands. While various waves of enclosure have reduced their extent, up until relatively recently, those that did remain were regulated by a set of stable institutions with ancient origins; with rights and duties falling on owners and rights holders and enforced through common law and the manorial court system. The rights system governing the commons had multiple aims, including economic output, equitable access, and community harmony and

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environmental sustainability (see Rodgers 2010; Winchester and Straughton 2010; Rodgers et al. 2011; Hodge 2016).

However, in 1965 the commons of England and Wales suffered a policy shock in the form of the Commons Registration Act 1965 that led to circumstances similar to Hardin's (1968) classic allegory of the *Tragedy of the Commons*. Specifically, it led to a situation where the sum of individual grazing rights were often far in excess of the carrying capacity of the common land, but there was no formal legal mechanism to restrict access to rights holders. In addition, some areas of land were no longer grazed due to difficulties in building and maintaining infrastructure such as fencing and cattle grids, leading to biodiversity loss and weed infestation (Natural England 2009a).

Within the institutional vacuum generated by the Commons Registration Act 1965, a number of commons associations were formed, often from the remnants of the pre-existing manorial institutions.[1] These voluntary groups were set up by commons rights holders themselves. They had no state authority and relied on their members to agree upon how the common should be managed. Only with unanimous agreement were they able to enter into legally binding agreements or guarantees (Defra 2017).

The policy shock generated by the Commons Registration Act 1965 provides an opportunity to test whether the voluntary commons associations that were formed in its wake were able to deliver sustainable grazing outcomes. We consider the results to be important to both the literature evaluating the effectiveness of voluntary associations and agreements to deliver improved environmental outcomes and to the commons literature.

Starting with the empirical and experimental literature on voluntary associations and agreements, results concerning their effectiveness in delivering improved environmental organisations appear inconclusive (Kotchen 2013; Schleich et al. 2016; Gallier et al. 2017; Kesternich et al. 2017). This is partly driven by the fact that many voluntary environmental organisations have multiple objectives. For instance, as noted by Baland and Platteau (1998) and Tachibana and Adhikari (2009), community values such as identity may be placed above sustainable resource management goals.[2] Indeed, while collective action is often necessary, it is not sufficient in itself for generating sustainable environmental outcomes. Another reason for the mixed results relates to significant empirical challenges, including the need to obtain accurate data on environmental performance and to address issues associated with selection

[1] See Bailey (2010) and Rodgers et al. (2011) for insights into the functioning of manorial courts, local custom, and other institutions predating the Commons Registration Act 1965. Manor courts were local meetings, called by the lord of the manor and presided over by his steward. Those holding land were required to attend and decisions were taken by a jury that comprised of tenants of the manor. Deliberations were grounded in the concept of 'the custom of the manor', which varied from place to place and normally governed tenure, transfers of land, and litigations between rights holders. Many manorial courts were already non-functional by the late nineteenth century, however local custom often continued in various forms. For example, in some cases, parish councils assumed responsibility for commons within their boundaries. In other cases, land owners and commoners established governance mechanisms, such as stintholder management committees. Rodgers et al. (2011: 20) note that '[l]ocal custom continued to interact with formal law until the capture of property rights in a fixed and static form as a result of the Commons Registration Act 1965.' They also note that voluntary commons associations proliferated in the late twentieth century in response to the Commons Registration Act 1965 and to coordinate involvement in agri-environmental schemes.

[2] For instance, some organisations may be primarily symbolic, more focused on building identity or cementing a link with the natural resource in question, rather than natural resource management itself.

bias that are likely to loom large in the formation of voluntary environmental associations (Rustagi et al. 2010; Kotchen 2013).[3]

Currently, much of commons literature employs case-study methodology (Poteete and Ostrom 2008). While the case-study method is undoubtedly rich in its insights and allows for the nuances of place- and time-specific processes to be uncovered, the data derived from case studies are not always suitable for hypothesis testing and are limited in their external validity (van Laerhoven 2010). Larger N-studies that allow for quantitative analysis are therefore highlighted as a means to complement the insights from case-studies and contribute to the commons literature (e.g. van Laerhoven 2010; Coleman 2011).

The second reason why these results are important is that they can help to shed light on the role of the state in relation to the formation and effectiveness of voluntary environmental organisations. Some, such as Mansbridge (2014), argue that the state is necessary to promote voluntary group formation and enable them to continue to be effective.[4] In terms of its necessity for enabling the formation of voluntary groups, Mansbridge (2014) argues that the state is needed to threaten to impose a governance solution if local parties cannot agree to come together—analogous to the 'bargaining in the shadow of the law' literature that sees parties voluntary agree on an outcome in the knowledge that a decision will be made for them if they do not (Mnookin and Kornhauser 1979). In terms of the voluntary association's continued effectiveness, Mansbridge (2014) argues that recourse to an external sanctioning authority is necessary as purely local sanctions will be insufficient to protect natural resources. This contrasts with some of the empirical literature that has shown that local groups who did not receive state support had improved environmental outcomes. For instance, Tachibana and Adhikari (2009) found that community based management groups in Nepal who did not receive official support had better natural resource management outcomes than those who did. Ito (2012) has also found similar results for community irrigation organizations in rural China. We also hope that our results add to the emerging field experimental literature on common pool resource management that primarily aims to investigate the crowding out effects of centralised interventions (see Vollan 2008; Velez et al. 2010; Lopez et al. 2012; Santis and Chávez 2015).

The remainder of this paper is as follows. In Sect. 2, we provide an outline of the institutional framework of the commons of England, including a brief account of how the commons associations function. In Sect. 3 we present our data and empirical methods. In Sect. 4 we present our results and in Sect. 5 we conduct a number of robustness checks. In Sect. 6 we discuss the importance of our results, both in terms of the literature and policy implications, which is then followed by a brief conclusion.

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[3] This is illustrated by the work of Rustagi et al. (2010), who by combining experimental data with environmental outcomes in Ethiopia, found that groups with larger shares of conditional cooperators have better forest management outcomes. This finding suggests that there are likely to be unobservable characteristics associated with voluntary group formation and environmental outcomes.

[4] While it is well known that Ostrom (1990) and the vast literature that she generated have documented numerous examples of how natural resource users at the local level can successfully overcome collective action problems, there remains debate over the degree that the state is needed to *enable* these outcomes. Mansbridge (2014) contends that Ostrom's central concept of polycentrism requires the state as an enabler to assist with the formation of the local group and the upholding of its rules. In particular, she contends that 'Ostrom's polycentric model assumes that some higher level than the local, which can threaten to impose other solutions, provide neutral information, provide venues and support for the local negotiation, and, crucially, sanction non-compliance.' There are good reasons to take this view as Ostrom (1990, 2009) herself highlights the necessity of punishing rule violators in her design principles for effective common governance. Furthermore, in such situations, important decisions would seem to require consensus, including the formation of the group itself, as there is little or no ability to enforce a majority decision on dissenters; they simply choose to walk away or to not abide with decisions (Larcom 2016).

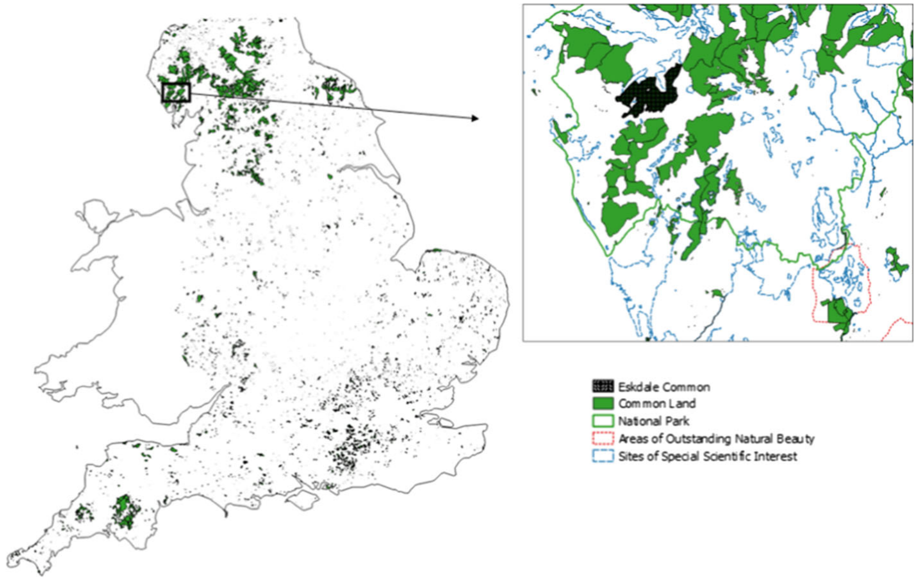

Fig. 1 Common land in England

2 Institutional Environment

In England, commons are privately owned parcels of land where third parties also have legally recognised use rights. They currently make up approximately 3% of total land area, and while they are scattered across the country; there are large concentrations in the northwest, southwest and southeast (see Fig. 1). Up until the Commons Registration Act 1965, commons were underpinned by a system of property rights where the lord of the manor owned the land and the local community (including farmers) held use rights that were enforced through manorial courts and common law (Rodgers et al. 2011). Within this legal framework, the rules of levancy and couchancy and stinting were practiced, along with the customary law principle of 'good neighbourhood', which provided a reflexive governance regime that is widely considered to have encouraged sustainable grazing practices (Bailey 2010; Rodgers 2010; Winchester and Straughton 2010; Rodgers et al. 2011; Hodge 2016). In terms of livestock, there were two specific mechanisms that encouraged sustainable practices. The first was the rule of levancy and couchancy that required commoners to only graze as many livestock on the common as could be kept over the winter months. The second was the practice of stinting, which consisted of grazing rights being defined by a fixed number of animals that could be adjusted in response to environmental factors.[5]

However, the Commons Registration Act 1965 required rightsholders to register their nominal access rights, that could then lawfully be unabatedly enforced regardless of the environmental conditions. This legislative change led to the discontinuance of the common

[5] While stinting consisted of a fixed number of animals it still allowed for flexible and reflexive governance of the commons. For instance, a fixed number of livestock that could be put on the common based on its carrying capacity could be established for a given time. Once this total amount was established, it could then be apportioned amongst rights holders. The Commons Registration Act 1965 destroyed the inherent ability of stinting to act as a reflexive mechanism to adjust grazing pressures in response to environmental factors (Rodgers et al. 2011).

law principles of levancy and couchancy and stinting from being legally binding.[6] This often saw the sum of individual grazing rights being far in excess of the carrying capacity of the common land, but there was no formal legal mechanism to restrict access to rights holders as before. Additionally, registration of common rights under the Act led to under-grazing in parcels of common land where there were now difficulties in investing in communal grazing infrastructure due to the breakdown of the previous institutional arrangement of managing common lands (Williams 2006; Natural England 2009b). The Commons Registration Act 1965 can therefore be seen to have effectively severed previous existing links between principles of sustainable management and common property rights (Rodgers 2010). While the UK government aimed to correct for the perverse outcomes generated by the Registration Act 1965 with the Commons Act 2006,[7] in the intervening period (the timeframe which is the focus of this study), persistent over-grazing in upland commons and under-grazing in lowland commons were highlighted as a severe threat to biodiversity (Short 2000; Natural England 2009b).

Following the shock generated by the Registration Act 1965, a number of voluntary commons associations were established across the country, where members agreed upon how the common should be managed and how their rules could be enforced.[8] Despite their voluntary nature, there is anecdotal evidence to suggest that they played (and continue to play) an important role in achieving sustainable land management on the commons where they operate. For instance, Rodgers et al. (2011) assessment of Eskdale Common (see Fig. 1) is that the commons association is the main management institution, including in terms of the design and enforcement of stocking rules that are refined and adapted to accommodate change. They found that many of the grazing rights follow pre-existing customary practices. In this respect they found that the commons register is largely irrelevant to graziers when calculating their use rights on the common, illustrating 'the secondary role that property law structures have on environmental management in the case study' (Rodgers et al. 2011: 102). Like many other commons in England, Eskdale is party to an agri-environmental agreement, and here they found that not only did the commons association help negotiate and secure the agreement but also administer it effectively, including dealing with potential free-rider activity and disputes among commoners. In addition to the presence of agri-environmental agreements, Eskdale common is also within the boundaries of a Site of Special Scientific Interest (SSSI) which places special obligations on landholders to protect the natural environment, which also needs to be accounted for when evaluating the effectiveness of the commons association.[9]

While the case of Eskdale common suggests that voluntary commons associations can be effective tools for sustainable natural resource management, up until now, it is not known

[6] Following their registration, rights to commons were no longer inherently reflexive and were incapable of meeting changing ecological conditions. Additionally, due to registration authorities rarely checking the rights that were registered, some rights holders were able to inflate or even invent grazing rights for registration (Rodgers 2010; Rodgers et al. 2011; Hodge 2016).

[7] Among other things, the Commons Act 2006 provided for the creation of statutory commons councils with powers to regulate grazing activities (Short 2008).

[8] Some commons associations evolved from manorial institutions, while others were established to collectively agree on the registration of common rights for the Commons Registration Act 1965 or to negotiate collective management schemes or management agreements (Rodgers et al. 2011).

[9] In addition to SSSI's, Areas of Outstanding Natural Beauty (AONB) and National Parks are designed to protect the natural environment and have the ability to affect environmental outcomes. In terms of numbers, 57% of the total area of common land is protected areas under the Sites of Special Scientific Interest (SSSI) designation by Natural England. 48% of the total area of common land is further designated as Areas of Outstanding Natural Beauty (AONB) and 30% of all common land is located within the boundaries of National Parks (Rodgers 2010).

whether this is an isolated case or evidence of a more systematic relationship. Furthermore, given the regulatory and institutional overlap that often exists within the commons of England, it is not clear what might be driving the environmental outcomes. If a robust systematic relationship can be established, it would provide valuable insights to the literature. It would also provide important insights for policy makers on whether voluntary associations can be left alone to deliver sustainable grazing outcomes or whether direct regulatory measures are necessary. Therefore, the remainder of this manuscript is dedicated to assessing whether voluntary commons associations are capable of achieving sustainable outcomes.

3 Data and Methods

We use historical spatial data on commons and land use outcomes sourced from the Biological Survey of the common lands in England (Defra 2012) and from the annual Farm Business Survey (Ministry of Agriculture, Fisheries and Food 2010) to investigate whether management by local commons associations is systematically associated with more sustainable grazing outcomes. We use two-stage least squares regression analysis to examine if commons associations have an effect on more sustainable grazing outcomes using economic heterogeneity as our instrumental variable.

3.1 Data Sources

3.1.1 The Biological Survey of the Common Lands in England

The biological survey of the common lands in England was compiled over a decade (1982–1993) by the Rural Surveys Research Unit at Aberystwyth University but only recently made publicly available. The survey contains extremely valuable biological, geographical, and regulatory data for 7052 parcels of common land sourced from the registers of common land, archives and field surveys.[10] 716 parcels of common land in the biological survey include field survey evaluations on grazing intensity based primarily on vegetation condition and quantified according to a six-category classification. A score of 1 or 2 was given to parcels of common land with low grazing intensity. A score of 3 or 4 was given to parcels of common land with medium grazing intensity. A score of 5–6 was given to parcels with high grazing intensity. According to Aitchison et al. (2000), commons judged as having low-grazing intensity can be considered to be under-grazed and commons judged to have high intensity can be considered overgrazed. We transform this measure of grazing intensity into a binary variable with 0 representing either under- or over-grazed intensities and 1 representing sustainable grazing outcomes. Our rationale for this comes from the poor environmental outcomes associated with both under-grazing and over-grazing. For example, under-grazing tends to lead to species invasion and a loss of biodiversity. Similarly, over-grazing tends to reduce vegetation, expose underlying soil and cause soil erosion (Williams 2006).

[10] Owing to the original objective of the survey and the scale of data collection, there are two caveats to using the dataset. Firstly, the data were designed to provide a broad overview of the situation facing common land in England. As a result, there is little insight into the intricacies of each parcel of common land (e.g. the exact nature of the rules enforced by commons associations) and how accurately the number of rights recorded in the commons registers matched up to the number of rights being exercised in practice. Secondly, the data were collected at different times over the course of the decade. This means that the dynamics of commons in respect to responding to both internal and external shocks are not captured in the data (Aitchison and Medcalf 1994; Aitchison et al. 2000).

Whether parcels were governed by local commons associations[11] were recorded for all 716 parcels of common land with a total of 48 parcels being recorded as governed by voluntary local commons associations during the survey period. Additional variables of interest in the survey include: whether or not there were disputes over rights of common among commoners; the number of grazing rights per hectare; the number of different types of rights[12] held; elevation; dominant habitat and livestock-type; and whether or not the parcel of common land falls partially or fully within the boundaries of an Area of Outstanding Natural Beauty (AONB), a Site of Special Scientific Interest (SSSI) or a National Park.

3.1.2 The Farm Business Survey

The farm business survey (FBS) is an annual survey that collects data from approximately 2300 farms in England and Wales. The survey covers the physical, environmental and economic performance of farm businesses (Defra 2017). We use spatial data from the farm business survey over the period 1982–1993 to construct measures of user attributes for our econometric analysis. Specifically, we construct measures of farmer age, farmer education, farm size, farm income, and environmental payments received (see Table 8). We also calculated our instrumental variable, non-livestock income heterogeneity of farms (economic heterogeneity), using data from the Farm Business Survey. To construct our measures, we first categorized individual farms by the lowest local unit of local administration in England (LAU1) for the years 1982–1993. For instance, taking our instrumental variable (economic heterogeneity) as an illustrative example, we calculated the Gini coefficient—a widely accepted measure of economic inequality—of non-livestock farm income for each LAU1 polygon over the period 1982–1993. We then averaged Gini coefficients for each LAU1 polygon over the period 1982–1993 before overlaying all parcels of common land. We assigned the Gini coefficient for each LAU1 polygon to the parcels of common land spatially located within respective LAU1 boundaries.[13]

3.2 Econometric Estimation

We begin by estimating the relationship between the management of local commons and sustainable grazing outcomes using a linear probability model. While a basic linear probability model is instructive for determining whether a statistical relationship exists between voluntary commons associations and sustainable grazing outcomes it has its limitations. Most importantly, there is likely to be endogeneity between the existence of commons associations and environmental outcomes. That is, it may be that better organized and more

[11] Commons associations are voluntary groups set up by commoners. These associations rely on members to determine how the common is managed and usually do not have any legal powers. If members unanimously agree, commons associations can engage in legally binding agreements, such as the Environmentally Sensitive Areas (ESA) payment scheme. Based on data from the commons registry, the average commons association in our sample has 30 rights holders.

[12] Rights include the right to pasture, estover, piscary, pannage, turbary and soil.

[13] Our approach has three potential limitations. The first limitation is that all farms in the FBS are randomly displaced by up to 10 km to ensure respondent confidentiality. This means that in a limited number of cases it is possible that farms will be allocated to an adjacent local administrative unit. A second potential limitation is that the overlayed farms are not spatially balanced among the 716 parcels of common land. Finally, our third limitation concerns the difference in the level of scale between parcels of common land and our instrument. Although we accept that this may lead to a loss in precision, we consider the FBS data and our methodology to be the most suitable approach to identifying an instrument for commons associations given the available data.

community spirited commons may be more likely to form voluntary commons associations. In such a situation, it becomes difficult to determine whether it is the voluntary commons associations themselves producing better environmental outcomes or some other underlying characteristics of the common. In such a case, the linear probability estimation will produce biased estimates because the variable capturing whether the common is managed by a voluntary commons association is likely to be correlated with the error term of the regression. In response to the potential problem of endogeneity, we employ a two stage least squares model to estimate a linear relationship between sustainable grazing outcomes and voluntary commons associations.

3.2.1 Linear Probability Regression Analysis

We estimate the relationship between the management of local commons and sustainable grazing outcomes using a linear probability model that takes the following form:

$$g_i = \alpha_0 + \beta_1 C_i + X_i' \Phi + \varepsilon_i \tag{1}$$

where g_i is a binary measure for sustainable grazing outcomes for individual common i, C_i measures whether individual common i has a voluntary commons association in place for the period of measurement, and $X_i^{'}$ is a vector of control variables.[14] We choose a linear probability model to produce results that are more consistent with the two stage least squares estimation below. In selecting our control variables, we draw on Ostrom's (2009) socio-ecological systems (SES) framework that identifies systems and sub-systems that affect the likelihood of resource users self-organising to achieve sustainable outcomes. Ostrom's SES framework consists of core sub-systems covering users, governance systems and resource systems and units which interact to produce a range of sustainability outcomes. These core sub-systems are further disaggregated into second-level variables.

We follow Ostrom's SES framework in grouping our control variables according to sub-system.[15] Starting with user-attributes, we include the number of users, farmer age, education, income and farm size. For governance systems, we include whether or not there were disputes over rights of common among commoners, the number of grazing rights per hectare, the number of different types of rights held, whether or not the parcel of common land falls partially or fully within the boundaries of an Area of Outstanding Natural Beauty (AONB), a Site of Special Scientific Interest (SSSI) or a National Park and average payments from the environmental sensitive areas (ESA) scheme. For resource systems and units, we include elevation, dominant habitat type, and livestock type.

3.2.2 Two-Stages Least Squares Regression Analysis

We employ a two stage least squares model to estimate a linear relationship between sustainable grazing outcomes and voluntary commons associations. The first and second-stage regressions are of the following form:

$$C_i = \alpha_0 + \gamma_1 Z_i + X_i' \Phi + u_i \tag{2}$$

$$g_i = \alpha_0 + \beta_1 C_i + X_i' \Phi + v_i \tag{3}$$

[14] Control variables calculated using data from the Farm Business Survey enter the regression model as the average value for each individual common *i*.

[15] Our selection of variables is limited to data availability from the Biological Survey of the Common Lands and the Farm Business Survey.

In these two equations, g_i is the measure for sustainable grazing outcomes, $X_i^{'}$ is a set of exogenous control variables (as outlined above), C_i is the endogenous measure for whether a voluntary commons association in place, Z_i is the instrumental variable (economic heterogeneity, which is discussed below), and u_i and v_i are the econometric errors, which contain unobservable factors that can either be related to the formation of voluntary commons associations, sustainable grazing outcomes, or both.

The parameter of interest is the second stage parameter β_1, which aims to measure the causal effect of commons associations on sustainable grazing outcomes. For this parameter to be identified, the instrument of economic heterogeneity must be both 'relevant' and 'valid'. Specifically, our instrument must be both correlated with the establishment of commons associations and have no effect on sustainable grazing outcomes other than through the establishment of commons associations.

Starting with the 'relevance' requirement, theoretical and empirical evidence suggests that we can expect economic heterogeneity to be associated with the establishment of local commons associations. While it is acknowledged that there is debate over the role that economic heterogeneity plays in relation to the promotion of community organizations, there seems little doubt that it is an important factor (e.g. Johnson and Libecap 1982; Tang 1994; Ruttan and Borgerhoff Mulder 1999; Vedeld 2000; Varughese and Ostrom 2001; Dayton-Johnson and Bardhan 2002; Kurien and Dietz 2004; Ruttan 2008; Andersson and Agrawal 2011; Ito 2012). In the context of the English commons we posit that economic heterogeneity allows for some 'privileged' commoners to be able to more easily absorb the start-up and running costs associated with a local commons association, and as will be seen in our results (Table 3), our measure of economic heterogeneity is strongly positively correlated with local commons associations.[16]

Turning to the second requirement of a good instrument, 'validity'. This requires that economic heterogeneity should exclusively affect sustainable grazing outcomes through its first stage impact on the establishment of commons associations. We consider this to be a defendable assumption in our case, as it is not apparent how economic heterogeneity (as we measure it—see below) could play a role in sustainable grazing outcomes, other than through better community organization that is manifested by the establishment of a commons association. While it is true that income levels may affect environmental preferences or capacity to undertake investments that protect the environment, there is no apparent reason why economic heterogeneity should. Given that economic heterogeneity may be linked to concentration of common use rights that may in turn be linked to grazing outcomes, we construct a measure that de-links this potential relationship.[17] We do this by excluding income derived from livestock in our measure of farm income that is used to construct our measure of economic heterogeneity. By excluding all income generated from livestock (whether on private or common land) we hope to exclude the potential for a direct relationship between income heterogeneity and management of common land, thus providing us with an

[16] In theory, a counter-argument could be made that commoners are less likely to engage in the establishment of commons associations (or engage for symbolic reasons only) since their economic situation does not depend heavily on the environmental quality of the common.

[17] For example, if we take the extreme case where one commoner owns all the access rights to a given parcel of land this would be akin to private property rights for that parcel and is therefore likely to result in a different level of grazing intensity than if grazing rights were dispersed evenly among a group of farmers.

instrument that should be valid.[18] As an additional check, we estimate an overidentified model using generalized method of moments (gmm) estimation. To do this, we disaggregate our economic heterogeneity variable into two components: crop income and off-farm income. We calculate the gini coefficient for each component and include the two measures of economic heterogeneity as our instruments. This allows for us to test the validity of our instruments using the Hansen J-statistic test.

4 Results

4.1 Summary Statistics

Table 1 reports summary statistics for our measures of sustainable grazing and local commons associations, as well as our user-, governance-, and resource-attribute variables. Summary statistics are also presented for our instrumental variable: economic heterogeneity. In our sample, we find that 331 (46%) of our parcels of common land are grazed sustainably and that 385 parcels are either under- or over-grazed. We also see that 48 parcels of common land are managed by a commons association.

4.2 Linear Probability Model

As can be seen in Table 2, commons associations are consistently linked with sustainable grazing outcomes at the 1 percent significance level across all estimation specifications using OLS. The coefficient is also highly consistent across specifications. Beginning with our first specification which includes no control variables (column 1) we find that commons associations are 36 percentage points more likely to be associated with sustainable grazing outcomes. When we include user attributes in our model (column 2), we continue to find commons associations to be statistically significant at the 1% level and commons associations are 39 percentage points more likely to be associated with sustainable grazing outcomes. In column 3 we control for governance attributes and find that commons associations are now 33 percentage points more likely to be associated with sustainable grazing outcomes. Controlling only for resource attributes (column 4), we find that commons associations are 36 percentage points more likely to be associated with sustainable grazing outcomes. In our preferred specification (column 5), we include all user-, governance- and resource-attribute control variables and find that commons associations are 36 percentage points more likely to be associated with sustainable grazing outcomes.[19]

4.3 Instrumental Variable Estimation

While the estimations above suggest a strong link between sustainable grazing and commons associations, they do not establish a causal relationship due to the potential for endogeneity. As discussed above, more cohesive and functional commons communities may be more prone

[18] Our instrumental variable is the heterogeneity of farm-income excluding income derived from livestock. We exclude income derived from livestock to de-link our instrumental variable from livestock income heterogeneity, which may be directly related to sustainable grazing outcomes. We consider our instrumental variable to be de-linked from livestock income heterogeneity as the correlation coefficient of our instrumental variable with livestock income heterogeneity is 0.186 and the correlation coefficient between our instrumental variable and total farm income heterogeneity (including income from livestock) is 0.564, respectively.

[19] We note that estimations using a logistic regression model produce similar results to our OLS estimates (see Table 8).

Table 1 Summary statistics

Variable	N	$N=1$	Mean	SD	Min.	Max.
Sustainable grazing	716	331	0.462	0.499	0	1
Overgrazing	716	195	0.272	0.445	0	1
Commons association	716	48	0.067	0.230	0	1
Economic heterogeneity	573	–	0.416	0.089	0.086	0.705
Economic heterogeneity (crop income)	497	–	0.527	0.143	0.29	0.841
Economic heterogeneity (off-farm income)	573	–	0.573	0.114	0.146	0.810
User attributes						
Age	618	–	49.471	4.183	48.278	51.546
Education (log)	618	–	2.519	0.076	2.485	2.565
Farm size (log)	618	–	4.772	0.643	4.477	5.216
Income (log)	618	–	10.220	0.485	10.043	10.531
Governance attributes						
Grazing rights per hectare	716	–	0.585	2.116	0	31.532
Rights disputes	716	183	0.256	0.437	0	1
Types of rights	716	–	1.824	1.565	0	7
AONB/SSSI/National Park	716	366	0.511	0.500	1	1
ESA payment (log)	618	–	8.597	0.757	8.025	9.173
Resource attributes						
Elevation	716	–	1.940	1.480	0.02	6.10
Dominant livestock	716	446	0.623	0.485	0	1
Dominant habitat	716	451	0.630	0.483	0	1

Minimum and maximum values are replaced by the 25th and 75th percentile values for all variables (economic heterogeneity, age, education, farm size, income, ESA payment) constructed using data from the Farm Business Survey in accordance with Defra data privacy conditions. Age and education are measured in years. Farm size is measured in hectares. Income and ESA payments are measured in British pounds. Elevation is measured in 100 s of metres

Table 2 Linear probability regression results

Variables	(1)	(2)	(3)	(4)	(5)
Commons association	0.358*** (0.066)	0.385*** (0.064)	0.325*** (0.066)	0.357*** (0.066)	0.355*** (0.067)
User attributes	No	Yes	No	No	Yes
Governance attributes	No	No	Yes	No	Yes
Resource attributes	No	No	No	Yes	Yes
N	716	611	675	716	611

The dependent variable is a binary measure where a value of 0 denotes either under- or over-grazing or a value of 1 denotes medium intensity grazing. User attributes include age, education, farm size, and income. Governance attributes include grazing rights per hectare, types of rights, rights disputes, AONB/SSSI/National Park and ESA payments. Resource attributes include elevation, dominant habitat and dominant livestock
***, ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively. Robust standard errors are presented in parentheses

Table 3 Main results: two-stage least squares

	(1)	(2)	(3)	(4)	(5)
Panel A: second stage					
Commons association	0.573** (0.285)	0.940*** (0.359)	0.515* (0.304)	0.611** (0.281)	0.843** (0.351)
Panel B: first stage					
Economic heterogeneity	0.780*** (0.152)	0.717*** (0.156)	0.740*** (0.141)	0.796*** (0.154)	0.714*** (0.148)
User attributes	No	Yes	No	No	Yes
Governance attributes	No	No	Yes	No	Yes
Resource attributes	No	No	No	Yes	Yes
AP/KP *F* Stat	26.380	21.156	27.394	26.782	22.488
N	573	565	573	573	565

The dependent variable is a binary measure where a value of 0 denotes either under- or over-grazing or a value of 1 denotes medium intensity grazing. User attributes include age, education, farm size, and income. Governance attributes include grazing rights per hectare, types of rights, rights disputes, AONB/SSSI/National Park and ESA payments. Resource attributes include elevation, dominant habitat and dominant livestock
***, ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively. Robust standard errors are presented in parentheses

to form commons associations. Therefore, we instrument for commons associations using a measure of economic heterogeneity (excluding livestock income).

Table 3 presents the results of an exactly identified two-stage least squares regression that mirrors the simple OLS regressions above; where in column 1 we do not include any control variables, in column 2 we include only our user-attribute variables, in column 3 we include only our governance-attribute variables, in column 4 we include only our resource-attribute variables, and in column 5 we include user-, governance- and resource-attributes. In terms of our first stage results it can be seen that our measure of economic heterogeneity is positively associated with commons associations across all specifications at the 1% statistical significance level. Indeed, the Angrist–Pischke (AP) F statistic has a value above 21 across each of the specifications suggesting that economic heterogeneity is an informative instrument (Staiger and Stocks 1997; Stock and Yogo 2005).

In terms of the second stage, we find commons associations to be positively associated with sustainable grazing outcomes across all specifications, with generally higher coefficients but with lower significance levels compared to our OLS regression results.[20] The fall in statistical significance is a result of much larger standard errors compared to the simple OLS regressions (approximately 5 times larger). This is to be expected with two-stage least squares regressions, as only part of the variation in commons management is used to explain sustainable management outcomes. In our preferred specification, which includes user-, governance- and

[20] The higher coefficient could be due to correcting for endogeneity contained within the OLS and/or the fact that the OLS and 2SLS estimate different effects. OLS estimates an average treatment effect (ATE), whereas the 2SLS estimates a local average treatment effect (LATE). The LATE is the effect of voluntary commons associations on sustainable grazing outcomes for those observations that were shifted by our instrument (non-farm income heterogeneity). This means that it is not an estimate for the entire sample, but only for a subset of observations (the set of 'compliers'). In particular, our IV estimates do not apply to those commons that would have adopted voluntary commons associations no matter what the value of the instrument was (the set of 'always-takers'), nor does it apply to those commons who would have never established a voluntary commons association no matter what the value of the instrument was (the set of 'never-takers').

resource-attributes as controls, we find commons associations to be positively associated with sustainable grazing outcomes at the 5% level with a coefficient of 0.843. That is, our results find that commons that have commons associations are approximately 84 percentage points more likely to produce sustainable grazing outcomes. Importantly, this result stands while controlling for individual characteristics of farmers that use the commons, wider governance characteristics (including regulatory overlap such as commons being in national parks) and geographical and biological attributes of the commons themselves (including elevation).

5 Robustness

Our estimates above show that commons governed by voluntary commons associations are much more likely to achieve sustainable grazing outcomes. However, it is acknowledged that these results depend on our measure economic heterogeneity being a valid instrument. They also depend on our operationalisation of 'sustainable grazing'. In this section we aim to demonstrate the robustness of our results. Firstly, we overidentify the estimated model by disaggregating our measure of economic heterogeneity into two separate instruments. Secondly, we estimate the relationship between voluntary commons associations and under-grazing and over-grazing using a multinomial logit regression. Thirdly, we estimate the relationship between voluntary commons associations and over-grazing only. Finally, we control for time stamps to take into account the fact that the data on sustainable grazing were collected over the course of a decade.

5.1 Overidentified Model

In an effort to test whether our instrument can be legitimately excluded from our estimated equation, we estimate an overidentified model using generalized method of moments (gmm) estimation. This allows for us to test the validity of our instrument (economic heterogeneity) using the Hansen J-statistic test. The Hansen J-statistic test is a heteroscedasticity robust joint null hypothesis test that the instruments are valid (e.g. uncorrelated with the error term). To do this, we disaggregate our economic heterogeneity variable into two components: crop income and off-farm income. We calculate the gini coefficient for each component and include the two measures of economic heterogeneity as our instruments. As shown in Table 4, we continue to find both measures of economic heterogeneity to be positively associated with commons associations across all specifications at the 1% significance level. We also continue to find commons associations to be positively associated with sustainable grazing outcomes at the 5% significance level. Turning to our results for Hansen's J test statistic, we find p values of 0.454–0.603 across all of our specifications. We therefore do not reject the null hypothesis that our instruments are valid.

5.2 Multinomial Logit Regression

As previously mentioned, in our main analysis we transformed the six-category measure of grazing intensity into a binary measure denoting sustainable grazing and unsustainable grazing (under- and over-grazing). As an additional robustness test, we make use of a more comprehensive distribution of our measure of sustainable grazing and investigate the statistical relationship between voluntary commons associations and grazing outcomes using a multinomial logistic regression. To do this, we collapse the six-category measure of grazing intensity into three categories: under-grazing (categories 1 and 2), sustainable grazing (cate-

Table 4 Overidentified gmm regression results

	(1)	(2)	(3)	(4)	(5)
Panel A: second stage					
Commons association	0.527** (0.222)	0.717** (0.281)	0.492** (0.249)	0.581** (0.239)	0.632** (0.294)
Panel B: first stage					
Economic heterogeneity (crop income)	0.481*** (0.091)	0.486*** (0.090)	0.449*** (0.088)	0.457*** (0.097)	0.451*** (0.096)
Economic heterogeneity (off-farm income)	0.344*** (0.116)	0.297*** (0.101)	0.292*** (0.108)	0.343*** (0.117)	0.298*** (0.108)
User attributes	No	Yes	No	No	Yes
Governance attributes	No	No	Yes	No	Yes
Resource attributes	No	No	No	Yes	Yes
AP/KP *F* statistic	14.574	14.769	14.375	12.191	11.842
Minimum eigenvalue statistic	32.487	22.586	25.415	27.663	19.145
Hansen's J test statistic (*p* value)	0.454	0.541	0.552	0.510	0.603
N	494	492	494	494	492

The dependent variable is a binary measure where a value of 0 denotes either under- or over-grazing or a value of 1 denotes medium intensity grazing. User attributes include age, education, farm size, and income. Governance attributes include grazing rights per hectare, types of rights, rights disputes, AONB/SSSI/National Park and ESA payments. Resource attributes include elevation, dominant habitat and dominant livestock

***, ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively. Robust standard errors are presented in parentheses

gories 3 and 4), and over-grazing (categories 5 and 6). We do this for two reasons. Firstly, we require a base category of sustainable grazing for comparison. Secondly, not all categories had sufficient observations to be included individually.

Our results are presented in Table 5. We find that voluntary commons associations are associated with a decreased probability of there being over-grazing relative to sustainable grazing at the 5% significance level. We also find that commons associations are associated

Table 5 Multinomial logistic regression results—average marginal effects

Variables	Undergrazing	Overgrazing
Commons association	− 0.179* (0.102)	− 0.214** (0.092)
User attributes	Yes	Yes
Governance attributes	Yes	Yes
Resource attributes	Yes	Yes
Log likelihood = − 664.515		
N = 611		

The dependent variable is a categorical measure where the base category is medium-intensity grazing. User attributes include age, education, farm size, and income. Governance attributes include grazing rights per hectare, types of rights, rights disputes, AONB/SSSI/National Park and ESA payments. Resource attributes include elevation, dominant habitat and dominant livestock

***, ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively. Robust standard errors are presented in parentheses

with a decreased probability of there being under-grazing relative to sustainable grazing at the 10% significance level. These results are robust to including user-, governance- and resource-attribute control variables and robust standard errors. Our results are consistent with our OLS and logistic regression estimations that use a binary variable of sustainable grazing.

5.3 Overgrazing

As discussed above, under-grazing imposes a threat to sustainable grazing practices for the commons of England and is therefore included in our measure for sustainable grazing outcomes in our main results. Under-grazing can lead to species infestation and is explicitly recognised as a threat to sustainable farming practices by a number of commons associations. One of the main causes for under-grazing is a lack of grazing infrastructure. For example, a report commissioned by Natural England (2009a) found that individual commoners in Exmoor were unwilling to graze some parcels of common land due to a lack of cattle grids, and that more generally a lack of fencing was a significant deterrent to individual commoners exercising their grazing rights. Investing in infrastructure (e.g. cattle grids, fences) can be often prohibitively costly for a given individual but could be an optimal strategy for the group as a whole.

Despite this, we acknowledge that over-grazing is most usually associated with the unsustainable management of commons, as popularized by Hardin's (1968) classic allegory. Therefore, we estimate the relationship between commons associations and overgrazing using the same exactly identified two-stage least squares approach as in our main results. As can be seen in Table 6, we find a negative and highly significant relationship. These results show that commons governed by voluntary commons associations are less likely to result in over-grazing. In our preferred specification, that includes all controls relating to user, governance and resource attributes, commons governed by voluntary commons associations are 94 percentage points less likely to result in over-grazing.

Table 6 Two-stage least squares results—overgrazing

	(1)	(2)	(3)	(4)	(5)
Panel A: second stage					
Commons association	− 0.948***	− 0.967***	− 0.972***	− 0.886***	− 0.937***
	(0.291)	(0.316)	(0.328)	(0.276)	(0.354)
Panel B: first stage					
Economic heterogeneity	0.780***	0.722***	0.710***	0.796***	0.648***
	(0.152)	(0.153)	(0.140)	(0.154)	(0.138)
User attributes	No	Yes	No	No	Yes
Governance attributes	No	No	Yes	No	Yes
Resource attributes	No	No	No	Yes	Yes
AP/KP *F* Stat	26.379	22.425	25.771	26.782	22.173
N	573	565	573	573	565

The dependent variable is a binary measure where a value of 0 denotes either under- or medium-grazing or a value of 1 denotes overgrazing. User attributes include age, education, farm size, and income. Governance attributes include grazing rights per hectare, types of rights, rights disputes, AONB/SSSI/National Park and ESA payments. Resource attributes include elevation, dominant habitat and dominant livestock

***, ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively. Robust standard errors are presented in parentheses

Table 7 Two-stage least squares controlling for time stamps

	(1)	(2)	(3)	(4)	(5)
Panel A: second stage					
Commons association	0.652** (0.274)	0.970*** (0.350)	0.599** (0.303)	0.667** (0.278)	0.837** (0.372)
Panel B: first stage					
Economic heterogeneity	0.890*** (0.005)	0.810*** (0.177)	0.821*** (0.156)	0.878*** (0.008)	0.752*** (0.166)
User attributes	No	Yes	No	No	Yes
Governance attributes	No	No	Yes	No	Yes
Resource attributes	No	No	No	Yes	Yes
Time stamps	Yes	Yes	Yes	Yes	Yes
AP/KP *F* Stat	27.298	20.966	27.790	26.673	20.590
N	514	506	514	514	506

The dependent variable is a binary measure where a value of 0 denotes either under- or over-grazing or a value of 1 denotes medium intensity grazing. User attributes include age, education, farm size, and income. Governance attributes include grazing rights per hectare, types of rights, rights disputes, AONB/SSSI/National Park and ESA payments. Resource attributes include elevation, dominant habitat and dominant livestock. Time stamps denote the year when grazing intensity data were recorded through a field survey

***, ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively. Robust standard errors are presented in parentheses

5.4 Time-Stamps

As previously noted, our grazing intensity data were collected over a decade. To make sure that the period in time at which data were collected for a given parcel does not systematically affect our results, we re-run our exactly identified two-stage least squares regression estimations controlling for time-stamps denoting when the grazing intensity data were collected from each parcel. As can be seen in Table 7, our results continue to be statistically significant at the 1 and 5% significance levels when controlling for time-stamps.

6 Discussion

Using two-stage least squares regression analysis we have found that commons governed by voluntary commons associations are approximately 84 percentage points more likely to produce sustainable grazing outcomes than those that are not. These results hold while controlling for the individual characteristics of farmers that use the commons, wider governance characteristics (including regulatory overlap such as commons being in national parks) and geographical and biological attributes of the commons themselves.

The policy shock generated by the Commons Registration Act 1965 provided us with an opportunity to test whether the voluntary commons associations that evolved as a result of the shock were able to achieve sustainable environmental outcomes. Our findings therefore make a quantitative contribution directly to both the literature evaluating the effectiveness of voluntary associations and agreements to deliver improved environmental outcomes and to the largely case-study-based commons literature. As noted by Kotchen (2013), the results on the efficacy of voluntary approaches to environmental management have been mixed to date and the literature suffers from empirical difficulties, most notably poor measurement and selection biases. We have been able to deal with the measurement issue by using the recently released Biological Survey of the Common Lands of England that provided detailed and scientific assessment of grazing outcomes on a sample of commons. In relation to the potential for selection bias, we use an instrumental variable approach. We consider that these approaches in tandem enable us to deal with the main empirical problems and to make a claim that voluntary commons associations lead to more sustainable grazing practices.

Our study complements the rich detail of case studies of voluntary commons associations and sustainable natural resource management. For example, the previously mentioned case study of Eskdale Common by Rodgers et al. (2011) sheds light on both the place- and time-specific processes resulting in the formation of the Eskdale voluntary commons association and on the role that its voluntary commons association played in improving the sustainability of grazing practices. Although such case study approaches are incredibly important and necessary in order to improve our understanding of the commons and their management, they do not allow for hypothesis testing and are limited in their external validity (van Laerhoven 2010). By using a unique dataset of 716 parcels of common land in England, our study allows for the scaling-up of local-level findings such as that of Eskdale Common by testing the hypothesis that voluntary commons associations lead to more sustainable grazing outcomes at the national-level.

While voluntary commons associations were found to markedly improve environmental sustainability outcomes, it is also noteworthy that the majority of commons in our sample do not have them.[21] These results taken together suggest that while voluntary environmental associations can be effective when they exist, they are relatively rare. In terms of policy implications, this suggests that direct government action may still be necessary if widespread environmental improvements are to be achieved. However, governments should proceed cautiously as there is a growing body of experimental literature on common resource management (see Lopez et al. 2012; Santis and Chávez 2015; Velez et al. 2010; Vollan 2008; Cardenas and Stranlund 2000) that highlights the potential crowding-out effects of government intervention on intrinsic motivation to govern commons. Furthermore, the work of Dal Bó et al. (2010) has shown that exogenously imposed governance regimes can be far less effective than those developed endogenously through democratic processes.

As an alternative to direct government regulation, governments could aim to foster the establishment of voluntary environmental associations more widely. This would involve a thorough understanding of the structural impediments to the formation of voluntary associations. In the English context, some of the key impediments to the establishment of voluntary commons associations appear to be (relatively) high establishment and running costs. This is as establishing voluntary commons associations can be particularly complex and time consuming because of the need to secure the participation of all rights holders, whether they are active users or not: a problem that is made even more complex when rights registered under the 1965 Act have been subsequently sold with no requirement to inform the register of the new rights holder. Other impediments to collective management include the reluctance of some inactive graziers to allow new binding rules that they feared might prevent their dormant rights from being exercised at a later date (Rodgers et al. 2011).

[21] We empirically investigated if there were any spillovers from parcels with voluntary commons associations to neighbouring parcels with respect to both the likelihood of voluntary commons associations being built and to grazing intensity using ordinary least squares and logistic estimation techniques. We were unable to find statistically significant evidence of spillovers.

It is hoped that some of the impediments to the formation of voluntary commons associations identified above will be addressed through the ongoing implementation of the 2006 Commons Act, in particular through the opportunity for commoners to establish Commons Councils without the need for unanimous agreement of all rights holders. Importantly this reform should reduce establishment costs by lowering search and negotiation costs (as not every single rights holder needs to be contacted and convinced to join the association for it to have binding rules), however it may increase them in other areas.[22]

It is worth noting that while we have aimed to deal with endogeneity through the use of an instrumental variable approach, there may be unobservable characteristics among the members of the current voluntary commons associations that differ from those who are not, and this has the potential to bias our results. For instance, Dal Bó et al. (2010) found that those more likely to vote for voluntary governance mechanisms are more likely to act cooperatively in an experimental setting, while Rustagi et al. (2010) has shown that groups with a higher share of conditional cooperators are more likely to have better forest outcomes. These studies suggest there may well be unobservable characteristics that link voluntary commons associations to sustainable grazing outcomes that we have been unable to control for. Nonetheless, we consider that we have provided some useful evidence linking voluntary commons associations to better environmental outcomes. As outlined earlier, we note that the existing literature is mixed on this issue.[23] Ultimately, we hope that our results help researchers and policy makers find the best institutional arrangements to govern the commons.

When assessing our results in terms of their broader applicability, some discussion of the institutional environment that the commons associations are situated within is also necessary. While it is true that the Commons Registration Act 1965 led to a 'direct' institutional vacuum in relation to commons management, other governance measures were instituted, and the broader institutional structure of English law remained in place. In terms of the establishment of commons associations, while the government did not incentivise their formation through the threat of intervention if a voluntary agreement could not be reached (indeed the opposite occurred in that they were a response to the withdrawal of a government regulatory framework), it did incentivise their incorporation through the establishment of agri-environmental schemes. These schemes provided funds to farmers for delivering sustainable farming outcomes and were only accessible to common rights holders when they coordinated themselves. In this sense the government provided a 'carrot' for voluntary associations rather than a 'stick' (as proposed by Mansbridge 2014).

The second important institutional factor relates to the English legal system as a whole. Commons associations are unincorporated bodies that do not have the legal power to bind a dissenting minority and they are only able to make a binding agreement to regulate livestock through unanimous participation amongst rights holders (Rodgers et al. 2011). However, if consensus to form an association can be achieved, the members of the commons associations can enter into a legally binding agreement that enables non-compliers and defectors to be

[22] The 2006 Commons Act may increase establishment costs in given that Commons Councils are statutory bodies with formal procedural requirements. There have been two Commons Councils established under the Commons Act 2006: Bodmin Moor Commons Council established in 2015 (Statutory Instrument 2015 No. 1515); and Brendon Commons Council established in 2013 (Statutory Instrument 2013 No. 2959). Defra are currently in discussions about a possible council in Cumbria and Northumberland (personal communication 3 January 2018).

[23] In addition to the literature cited above, it should also be noted that the literature analysing voluntary international environmental agreements governing regional and global commons suggests they are merely ratifying business-as-usual outcomes (see Kellenberg and Levinson 2014).

punished through the courts. Therefore, while the voluntary commons associations were unable to sanction non-compliers directly (other than through the use of social sanctions) they could use legal action (or threat of it) to enforce their rules. This highlights the potential importance of a well-functioning legal system in providing an 'institutional infrastructure' that enables voluntary environmental associations to continue to be effective in delivering environmental benefits once an agreement has been made.

7 Conclusion

The 1965 Commons Registration Act was a policy shock that led to the removal of the capacity of commoners to regulate the intensity of grazing via traditional legal means. In response to this shock a number of voluntary commons associations were formed. Using spatial environmental and socio-economic data, we investigate whether these voluntary commons associations were able to deliver improved environmental sustainability outcomes. Using an instrumental variable approach, we find that commons governed by voluntary associations were approximately 84 percentage points more likely to produce sustainable grazing outcomes. These results are robust to the existence of a variety of controls, including the existence of overlapping institutional frameworks. Our results make an important quantitative contribution to the literature evaluating the effectiveness of voluntary associations and agreements to deliver improved environmental outcomes. At the same time, our results complement the rich detail of case studies found in the commons literature by testing the hypothesis that voluntary commons associations are causally related to more sustainable grazing outcomes at the national-level. In terms of policy implications our results are more mixed. This is as while our results show that voluntary associations can deliver more environmentally sustainable outcomes, voluntary associations themselves are relatively rare. This suggests that either direct government regulation is necessary (with the risk of crowding out current informal practices and intrinsic motivation) or governments must be more proactive in encouraging the formation and operation of voluntary commons associations by lowering establishment and running costs.

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Appendix

Tables 8 and 9.

Table 8 Logistic regression results—average marginal effects

Variables	(1)	(2)	(3)	(4)	(5)
Commons association	0.391*** (0.094)	0.427*** (0.095)	0.359*** (0.091)	0.391*** (0.093)	0.396*** (0.093)
User attributes	No	Yes	No	No	Yes
Governance attributes	No	No	Yes	No	Yes
Resource attributes	No	No	No	Yes	Yes
Log-likelihood	− 484.074	− 408.106	− 446.981	− 483.429	− 396.948
N	716	611	675	716	611

The dependent variable is a binary measure where a value of 0 denotes either under- or over-grazing or a value of 1 denotes medium intensity grazing. User attributes include age, education, farm size, and income. Governance attributes include grazing rights per hectare, types of rights, rights disputes, AONB/SSSI/National Park and ESA payments. Resource attributes include elevation, dominant habitat and dominant livestock
***, ***, ** and * denote statistical significance at the 1, 5 and 10% levels, respectively. Robust standard errors are presented in parentheses

Table 9 Data glossary

Variable	Description	Data source
Sustainable grazing	A binary variable with 0 representing either under- or over-grazing intensities and 1 representing medium-grazing intensity	Biological survey of the common lands of England (Defra 2012)
Overgrazing	A binary variable with 0 representing either under- or medium-grazing and 1 representing overgrazing	Biological survey of the common lands of England (Defra 2012)
Grazing (MNL estimation)	A categorical variable with 0 representing under-grazing, 1 representing medium-grazing and 2 representing over-grazing	Biological survey of the common lands of England (Defra 2012)
Commons association	A binary variable where a value of 1 indicates that the common land parcel is managed by a commons association. A value of 0 indicates that the parcel was not managed by a commons association	Biological survey of the common lands of England (Defra 2012)
Economic heterogeneity (income)	The Gini coefficient of farm income excluding income derived from livestock. The average value for each LAU1 polygon is assigned to the parcels of common land spatially located within the respective LAU1 boundaries	Farm Business Survey (Defra 1982–1993)
Economic heterogeneity (crop income)	The Gini coefficient of crop income. The average value for each LAU1 polygon is assigned to the parcels of common land spatially located within the respective LAU1 boundaries	Farm Business Survey (Defra 1982–1993)
Economic heterogeneity (off-farm income)	The Gini coefficient of off-farm income. The average value for each LAU1 polygon is assigned to the parcels of common land spatially located within the respective LAU1 boundaries	Farm Business Survey (Defra 1982–1993)
Age	Farm owner age. The average value for each LAU1 polygon is assigned to the parcels of common land spatially located within the respective LAU1 boundaries	Farm Business Survey (Defra 1982–1993)
Education (log)	The logarithm of the number of years of farm owner education. The average value for each LAU1 polygon is assigned to the parcels of common land spatially located within the respective LAU1 boundaries	Farm Business Survey (Defra 1982–1993)
Farm size (log)	The logarithm of total farm size. The average value for each LAU1 polygon is assigned to the parcels of common land spatially located within the respective LAU1 boundaries	Farm Business Survey (Defra 1982–1993)
Income (log)	The logarithm of total net farm income. The average value for each LAU1 polygon is assigned to the parcels of common land spatially located within the respective LAU1 boundaries	Farm Business Survey (Defra 1982–1993)
Grazing rights per hectare	Number of grazing rights divided by the total area (ha) of the common land parcel	Biological survey of the common lands of England (Defra 2012)

Table 9 continued

Variable	Description	Data source
Rights disputes	A binary variable where a value of 0 denotes no dispute over rights of common land are recorded in the common land registry and a value of 1 denotes that a dispute over rights of common land is recorded	Biological survey of the common lands of England (Defra 2012)
Types of rights	A categorical variable (ranging from 0 to 7) representing the number of different types of rights represented for each parcel of common land	Biological survey of the common lands of England (Defra 2012)
AONB/SSSI/National Park	A binary variable where a value of 1 indicates that at least some of the common land parcel falls within the boundaries of an Area of Outstanding Natural Beauty, Site of Special Scientific Interest or National Park and 0 represents no overlap	Biological survey of the common lands of England (Defra 2012)
ESA payment (log)	The logarithm of total payments from the Environmentally Sensitive Areas (ESA) scheme. The average value for each LAU1 polygon is assigned to the parcels of common land spatially located within the respective LAU1 boundaries	Farm Business Survey (Defra 1982–1993)
Elevation	The median elevation of each parcel of common land in 100 s of metres	Biological survey of the common lands of England (Defra 2012)
Dominant habitat	A binary variable where a value of 1 represents habitats amenable to grazing (grasslands, tall herbs and fern) and 0 represents all other habitats	Biological survey of the common lands of England (Defra 2012)
Dominant livestock	A binary variable where a value of 0 represents sheep and a value of 1 represents cattle, horses or ponies	Biological survey of the common lands of England (Defra 2012)
Time stamp	A continuous variable representing the year during which grazing intensity was recorded through a field survey	Biological survey of the common lands of England (Defra 2012)

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