



HAL
open science

Theoretical and empirical analysis of dedicated and food chain included payments for environmental services

Fanny Le Gloux

► **To cite this version:**

Fanny Le Gloux. Theoretical and empirical analysis of dedicated and food chain included payments for environmental services. Economics and Finance. Agrocampus Ouest, 2023. English. NNT : 2023NSARE063 . tel-04337587

HAL Id: tel-04337587

<https://theses.hal.science/tel-04337587v1>

Submitted on 12 Dec 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License

THESE DE DOCTORAT DE

L'INSTITUT AGRO RENNES ANGERS

ECOLE DOCTORALE N° 597

Sciences économiques et sciences de gestion - Bretagne

Spécialité : Sciences économique

Par

Fanny LE GLOUX

Theoretical and empirical analysis of dedicated and food chain included payments for environmental services

Thèse présentée et soutenue à Rennes, le 17 janvier 2023

Unité de recherche : SMART, INRAE

Rapporteurs avant soutenance :

Pierre COURTOIS Directeur de recherche, INRAE
Bettina MATZDORF Professeure, ZALF

Composition du Jury :

Président :	Damien ROUSSELIERE	Professeur, L'Institut Agro Rennes-Angers
Examineurs :	Laure KUHFUSS Mary RYAN Lionel VEDRINE	Researcher, James Hutton Institute Researcher, Teagasc Chargé de Recherche, INRAE
Dir. de thèse :	Pierre DUPRAZ	Directeur de Recherche, INRAE
Co-enc. de thèse :	Elodie LETORT	Chargée de Recherche, INRAE



THEORETICAL AND EMPIRICAL ANALYSIS OF DEDICATED AND FOOD CHAIN INCLUDED PAYMENTS FOR ENVIRONMENTAL SERVICES

Thèse de doctorat de l'institut national d'enseignement supérieur pour l'agriculture,
l'alimentation et l'environnement, école interne l'Institut Agro Rennes-Angers

Sciences Economiques et sciences De Gestion, spécialité Economie

Unité de Recherche :

Structures et Marchés Agricoles, Ressources et Territoires,
4 allée Adolphe Bobierre, 35011 Rennes, France

Présentée par :

Fanny LE GLOUX

Le 17 janvier 2023

Jury :

Directeur de thèse	Pierre Dupraz	Directeur de recherche, INRAE
Co-encadrante de thèse	Elodie Letort	Chargée de Recherche, INRAE

Président	Damien Rousselière	Professeur, L'Institut Agro Rennes-Angers
Rapporteur	Pierre Courtois	Directeur de recherche, INRAE
Rapporteuse	Bettina Matzdorf	Professeure, ZALF
Examinatrice	Laure Kuhfuss	Researcher, James Hutton Institute
Examinatrice	Mary Ryan	Researcher, Teagasc
Examineur	Lionel Védrine	Chargé de Recherche, INRAE

This Ph.D. thesis should not be reported as representing the views of l'Institut Agro Rennes - Angers. The views expressed are those of the author and do not necessarily reflect those of the University.

L'Institut Agro Rennes-Angers n'entend donner aucune approbation ni improbation aux opinions émises dans cette thèse. Ces opinions doivent être considérées comme propres à leur auteur.

Remerciements

Je voudrais remercier Pierre Dupraz et Elodie Letort qui ont encadré cette thèse. Merci de votre confiance et de m'avoir laissé beaucoup d'autonomie dans mon travail. C'était un grand moteur de ma motivation au quotidien. Pierre, merci pour tes conseils bienveillants et ton enthousiasme à partager tes connaissances. Même s'ils se sont parfois fait rares, nos échanges m'ont toujours fait beaucoup progresser. Elodie, merci pour ta réactivité, ton enthousiasme et ta franchise. Tes intuitions m'ont souvent aidé à prendre des décisions et me relancer en période de doute. Je te remercie aussi de m'avoir encouragé à postuler à cette thèse (encore une fois, ton intuition) !

Je remercie Douadia Bougherara, Philippe Bontems et Thomas Poméon pour leur intérêt, leurs encouragements, et leur bienveillance lors des comités de suivi de thèse. La préparation et le déroulé de ces points d'étapes annuels ont été décisifs dans la construction progressive du fil directeur de la thèse. Je suis également très reconnaissante à Pierre Courtois, Laure Kuhfuss, Bettina Matzdorf, Damien Rousselière, Mary Ryan et Lionel Védrine d'avoir accepté de faire partie de mon jury de thèse. Merci à Sabine Duvaleix, Alice Issanchou, et Carole Ropars-Collet, avec qui j'ai eu le plaisir de travailler sur les chapitres 3 et 4 de cette thèse.

Je souhaite remercier Marie Laporte pour sa participation aux travaux préliminaires sur le programme Eco-Méthane dans le cadre de son stage de M1, et Florian Martial pour son investissement dans la préparation et la conduite de l'expérience de choix dans le cadre de son stage de M2. Un grand merci aux étudiants de l'Institut Agro Rennes-Angers et aux employés de l'association TRAME ayant participé à la collecte des données du chapitre 3. Je remercie également les membres de l'ODR pour leur aide dans l'accès aux données du CASD. Merci à toutes celles et ceux qui ont fait progresser mes travaux par leurs conseils lors des conférences auxquelles j'ai eu la chance de contribuer. En particulier, je remercie Anastasio Villanueva pour ces précieux conseils sur les analyses des expériences de choix lors de la réunion 2022 du réseau REECAP. Merci à Marie Lassalas, Mathilde Fromage, Julia Jouan et Chantal Le Mouël pour leur relecture attentive et affûtée des différents chapitres de ce manuscrit.

Je remercie mes collègues de SMART avec qui j'ai aimé partager mon « quotidien » (mot qui mérite des guillemets car entremêlé de longues périodes de confinement et de télétravail). En particulier, je souhaiterais remercier Carl Gagné et Alain Carpentier pour avoir permis aux doctorants de continuer à venir travailler en présentiel le plus possible durant les longs mois de pandémie. Je suis également très reconnaissante à Françoise Auffray et Cécilia Marquer pour

leur aide et leur accompagnement, notamment lors de ma mobilité en Autriche, et pour ce fameux ordre de mission reliant Rennes et Uppsala en train et en bateau. Merci à Anne Chauvel pour son investissement à trouver une solution au mystère de ma webcam. Merci à toutes celles et ceux qui sont ou furent mes collègues de CDD pendant ma thèse et avec qui j'ai pu passer des moments si chouettes, au bureau comme en dehors. Mille mercis en particulier à Ahmet Candemir, Charlotte Chemarin, Julia Denantes, Esther Devilliers, Jean-François Dewals, Mathilde Fromage, Francesco Guerra, Lucile Henry, Julia Jouan, Victor Kieffer, Marie Lassalas, Abdel Ossen, Mathilde Roignant, Romaric Sodjahin et Lucille Steinmetz.

Merci à Rennes Métropole de m'avoir octroyé une bourse pour réaliser une mobilité en Autriche. Par-delà les frontières, je remercie donc chaleureusement les membres de l'Institute of Agricultural and Forestry Economics (AFO) de l'Université BOKU à Vienne. Je remercie Jochen Kantelhardt de m'avoir accueilli dans son équipe. Merci à Laura Eckart, Michael Eder, Michaela Grötzer, Sabine Muhr, Andreas Niedermayr, Sarah Oberdorfer, Verena Scherfranz, Fritz Wittmann et Julian Zeilinger pour votre gentillesse. C'était un réel plaisir de passer ces 4 mois avec vous au sein de votre magnifique campus ! Je dédie un remerciement particulier à Theresa Eichhorn et Lena Schaller, avec qui j'ai pu étroitement collaborer dans le cadre du projet CONSOLE. J'ai énormément appris et été inspirée à vos côtés. Je prolonge mes remerciements à l'ensemble des membres du projet CONSOLE, grâce à qui j'ai pu trouver un sens collectif à mon travail de thésarde parfois si solitaire.

Enfin, je remercie celles et ceux qui m'ont offert des bouffées d'air ces trois dernières années ! Merci à Fabio Ficareli, Yulya Samigullina et Alexandra Proskurina pour cette semaine de retrouvailles à Berlin en mars 2020. Une semaine plus tard, les frontières européennes se ferment. Deux ans plus tard, la guerre revient séparer nos pays. Et nous on buvait des bières au bord de la Spree. Un merci collectif aux ptits loups d'ACO, mes amis de l'agro, pour ces week-ends qui me font toujours un bien fou ! Je remercie Theresa Eichhorn avec qui j'ai planifié ce Crazy June 2022 entre la Suède et l'Italie, et sa famille qui m'ont si chaleureusement invité chez eux. Merci à mes presque sœurs Yinjie Zhu et Carol Sangolqui. Yinjie, merci de m'avoir amené au ski pour la première fois à 26 ans, toute bretonne que je suis. Merci à Bleuenn Aulnette et à Svetlana Bellanger, qui me connaissent par cœur depuis toutes ces années. Merci à Cécile Richard pour les sorties courses ponctuées par nos bobos respectifs.

Last but not least...je ne remercierai jamais assez mes parents et mon frère qui m'ont toujours soutenu et fait confiance de manière inconditionnelle. Ni eux ni moi ne comprenons tout à fait comment j'ai fini par faire une thèse en économie, encore moins à 6 km de la maison !

Funding

This PhD was co-financed by the Economics and social sciences (ECOSOCIO) division of the INRAE, and the Horizon 2020 research and innovation programme of the European Union under Grant Agreement No. 817949 (CONSOLE project, <https://console-project.eu/>).

Synthèse

Chapitre 1. Introduction générale

L'agriculture est intrinsèquement reliée aux ressources naturelles et aux écosystèmes. Pour produire de la nourriture, les activités agricoles prélèvent des ressources des écosystèmes naturels, et utilisent des intrants dérivés de l'extraction de ressources naturelles. L'agriculture bénéficie également de services écosystémiques de support (photosynthèse, cycles des nutriments et de l'eau, formation et fertilité des sols, biodiversité génétique) et de régulation (pollinisation, lutte contre les maladies et les ravageurs, purification de l'eau, décomposition, climat). En outre, l'agriculture contribue à façonner les paysages et à modifier les habitats naturels, et libère des gaz à effet de serre (GES), des produits chimiques et des nutriments dans l'environnement (eau, air, sol) (Heal and Small, 2002; Lichtenberg, 2002; Millennium Ecosystem Assessment, 2005; Therond et al., 2017). Ces perturbations des cycles du carbone, de l'azote, du phosphore et de l'eau affectent le climat et les habitats en entraînant une pollution et une vulnérabilité accrue aux risques naturels (Abu Hatab et al., 2022; Bezner Kerr et al., 2022; EEA, 2019). En Europe, le secteur agricole est le deuxième contributeur aux émissions de GES (EEA, 2022), le premier contributeur à la pollution diffuse des eaux (EEA, 2021), et souvent la principale source de pression sur les habitats et les espèces (EEA, 2020a; IPBES, 2019). En retour, les effets à court et long termes de la dégradation des écosystèmes et du changement climatique affectent les capacités de production agricole (Bezner Kerr et al., 2022).

Les multiples interactions entre les activités agricoles et les écosystèmes naturels font du secteur agricole à la fois un producteur de denrées alimentaires et un fournisseur de biens (et de maux) publics, dont les bénéfices (et les dommages) sont disponibles et accessibles à de nombreuses personnes au-delà des limites de l'exploitation (Cooper et al., 2009). Ces biens publics comprennent des habitats pour une diversité d'espèces (flore et faune des milieux agricoles), le stockage à long terme du carbone dans les sols et les éléments paysagers, et la protection de la qualité des sols et de l'eau des bassins versants. Depuis la montée des préoccupations environnementales mondiales dans les années 1970, les scientifiques ont accumulé des connaissances approfondies sur les interactions entre les systèmes agricoles et l'environnement, et sur les pratiques des agriculteurs qui atténuent les pressions sur les écosystèmes (Altieri, 1995). Les préoccupations environnementales et les solutions étant bien identifiées, le défi consiste aujourd'hui à généraliser leur adoption et à financer la transition.

Les paiements pour services environnementaux (PSE) sont des instruments aidant financièrement les agriculteurs à adopter des pratiques plus respectueuses de l'environnement. Ils reconnaissent les interventions volontaires des agriculteurs contribuant aux biens publics tels que l'atténuation du changement climatique, la qualité de l'eau et la préservation de la biodiversité, comme des services environnementaux (SE), pour lesquels ils peuvent recevoir un paiement. Les SE sont fournis conjointement avec les produits agricoles (production jointe). Dans un contexte de dégradation générale de la fourniture de biens publics par l'agriculture, il existe un consensus sur le fait que les SE sont soumis à une défaillance du marché. Les PSE viennent à corriger cette insuffisance. Les systèmes de PSE introduisent des mécanismes de financement pour mobiliser le consentement à payer (CAP) pour les SE, d'une part, et des mécanismes de paiement pour encourager les agriculteurs à fournir des SE, d'autre part (Pagiola and Platais, 2002). Les PSE sont des transactions volontaires entre fournisseurs de SE et des contributeurs, conditionnées à la mise en œuvre d'un ensemble de règles convenues pour générer des services (biens publics) au-delà des limites de l'exploitation agricole (S. Wunder, 2015). Les PSE sont des outils permettant de répondre à l'offre et à la demande de biens publics agroenvironnementaux et climatiques, et visent à accompagner une transition agroécologique à grande échelle vers une meilleure fourniture de ces biens par le secteur agricole.

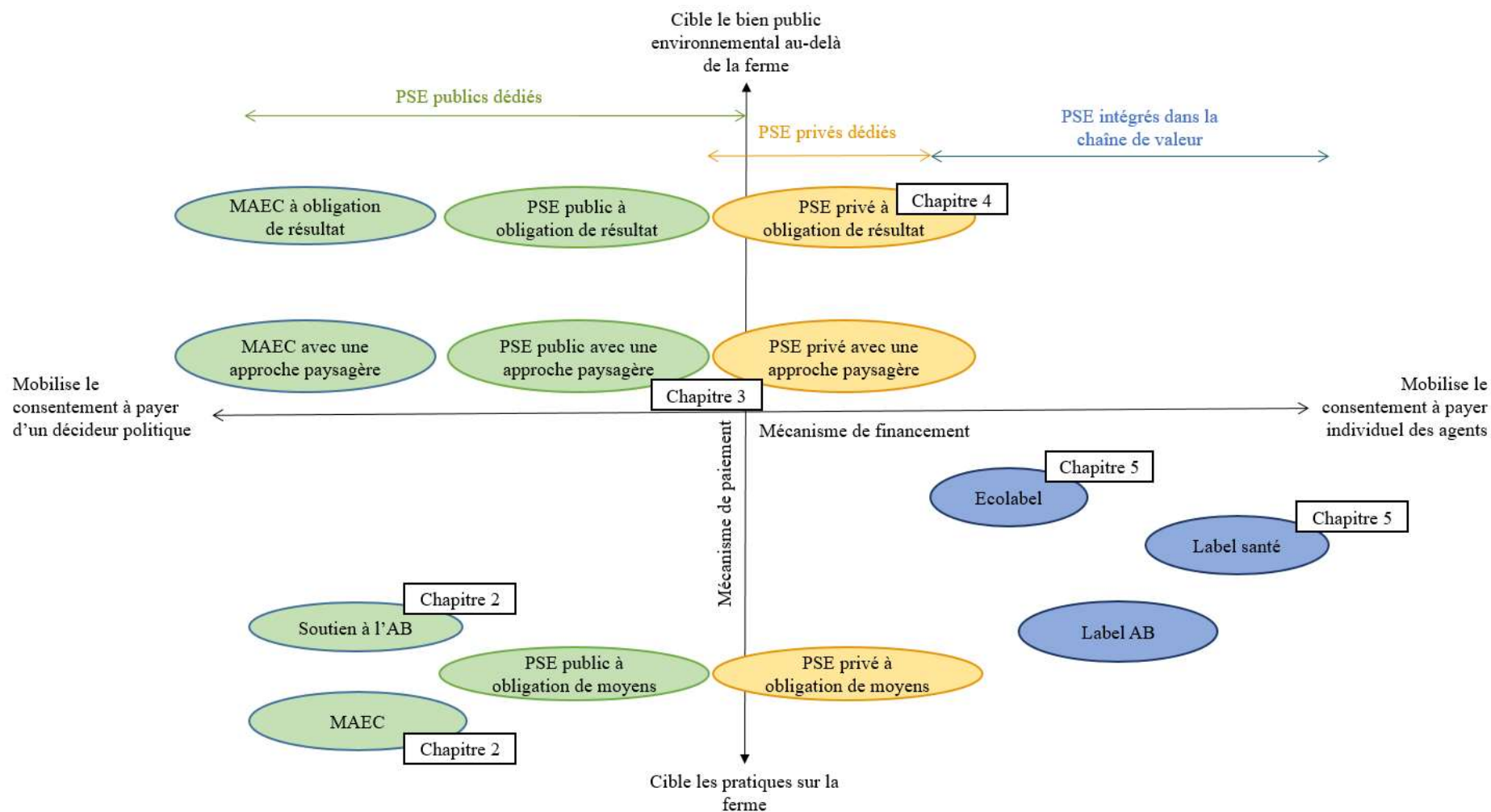
Trois problèmes principaux d'inadéquation entre l'offre des agriculteurs et la demande sociale ont été identifiés avec les PSE dominants actuels, que sont notamment les mesures agro-environnementales et climatiques (MAEC) de la politique agricole commune (PAC) (dispositifs publics dédiés). Premièrement, les mécanismes de financement ne permettent pas de capturer suffisamment de CAP pour répondre à la demande des agriculteurs et favoriser une adoption à grande échelle par les agriculteurs (faible demande des contributeurs) (Cullen et al., 2018; Duval et al., 2016; Uthes and Matzdorf, 2013; Zimmermann and Britz, 2016). Deuxièmement, les mécanismes de paiement tendent à conditionner le paiement à la mise en place de pratiques imposées au sein d'une exploitation individuelle (obligation de moyens), souvent peu ambitieuses, ce qui ne favorise ni l'efficacité environnementale, ni le dépassement des effets de seuils permettant la fourniture de bénéfices publics (faible offre de biens publics) (Cullen et al., 2018; Dupraz et al., 2009; Uthes and Matzdorf, 2013; Zavalloni et al., 2019). Troisièmement, les règles actuelles des aides publiques contraignent le paiement à être une compensation plutôt qu'une incitation, ce qui rend l'adoption des PSE non rentable pour de nombreux agriculteurs (faible offre de SE) (Duval et al., 2016).

De nouveaux types de PSE laissent entrevoir des leviers potentiels d'amélioration. Une demande plus forte de la part des contributeurs peut être exprimée en consacrant davantage de fonds publics aux aides environnementales (renforcement des dispositifs publics dédiés) (Dupraz and Guyomard, 2019; Matthews, 2013), et/ou en développant des mécanismes de financement qui captent un CAP privé (PSE privés dédiés ou intégrés dans la chaîne de valeur) (Duval et al., 2019b; Eichhorn et al., 2022). En outre, la fourniture de biens publics et l'efficacité environnementale des PSE peut être améliorée en conditionnant le paiement à la réalisation de dynamiques collectives au sein des agriculteurs d'un même ensemble paysager (approche paysagère), et/ou à la réalisation d'un résultat environnemental (Burton and Schwarz, 2013; Chaplin et al., 2021; Eichhorn et al., 2022; Matzdorf and Lorenz, 2010; Westerink et al., 2017).

L'objectif de ma thèse est d'analyser avec des approches théoriques et empiriques, l'efficacité de deux cas polaires de PSE : (i) la rémunération par les pouvoirs publics des SE volontaires des agriculteurs (dispositifs publics dédiés), (ii) la création d'un label sur un produit agricole visant à rémunérer un SE par les consommateurs (dispositifs intégrés dans la chaîne de valeur).

Dans ma thèse, j'évalue différents leviers permettant d'accroître l'adoption des PSE par les agriculteurs, en abordant spécifiquement les limites et les inefficacités des mécanismes actuels identifiés dans la littérature : (i) augmenter le budget alloué aux instruments publics actuels de PSE dans la PAC (chapitre 2), (ii) introduire des incitations favorisant une dynamique collective dans les mécanismes de paiement ciblant des biens publics avec des effets de seuils écologiques (chapitre 3), (iii) concevoir des mécanismes de paiement basés sur les résultats (chapitre 4). Pour compléter le financement public limité et les contributions volontaires insuffisantes des acteurs privés, je propose de capter davantage de contributions de la part des consommateurs en développant des labels officiels contenant des informations sur les bénéfices privés (ex : santé) de la consommation de denrées agricoles produites conjointement aux SE (chapitre 5).

Je défini une grille d'analyse des PSE selon deux dimensions (Figure S1) : (i) le ciblage du mécanisme de paiement, (ii) le mécanisme de financement mobilisant le CAP des contributeurs.



PSE: paiements pour services environnementaux
 MAEC : mesures agro-environnementales et climatiques
 AB: agriculture biologique

Figure S.1. Mécanismes de paiements pour services environnementaux pour remédier à la sous-provision des biens publics par l'agriculture.

Le premier axe permet de situer un PSE selon que le paiement est conditionné par les moyens mis en œuvre par les exploitations individuelles (ciblage des pratiques sur l'exploitation) ou par le bénéfice environnemental hors exploitation (ciblage du bien public environnemental au-delà de l'exploitation). Par exemple, il différencie les PSE à obligation de moyens (ex : paiement à l'hectare pour ne pas retourner une prairie) des PSE à obligation de résultat (ex : Eco-Méthane avec un paiement proportionnel à la réduction des émissions de méthane entérique par litre de lait). Je situe les approches paysagères au centre de cet axe, car elles sont ciblées sur des réalisations impliquant plusieurs agriculteurs et vont au-delà des limites de l'exploitation individuelle, mais peuvent inclure des exigences de pratiques ou de résultats environnementaux selon la conception du dispositif. Le deuxième axe classe les PSE selon qu'ils sont financés par le contribuable (mobilisation d'un CAP agrégé au nom des bénéficiaires du bien public) ou par des contributeurs volontaires suivant leur CAP individuel (mobilisation du CAP d'un agent selon ses propres préférences). Ce deuxième axe différencie les deux cas polaires de PSE, à savoir les MAEC financées par la PAC et la prime de prix payée par les consommateurs d'un produit labellisé dont la production est jointe à des SE. Sur la base de cette grille de lecture, je formule quatre questions de recherche que je développe dans quatre articles de recherches.

Question de recherche 1 : Les MAEC peuvent-elles être renforcées en ciblant davantage de fonds publics vers la fourniture de biens publics ?

Le premier mécanisme de PSE analysé est le soutien public dédié aux engagements environnementaux volontaires des agriculteurs dans le cadre de la politique agricole commune (PAC). Les données empiriques montrent qu'il existe un écart entre les priorités déclarées de la PAC et leur budget relatif. En particulier, le budget consacré au soutien des pratiques agricoles respectueuses de l'environnement est faible par rapport au budget des paiements directs aux agriculteurs qui ne sont pas ou peu conditionnées à des exigences environnementales.

Le chapitre 2 se concentre sur un scénario d'évolution de répartition du budget de la PAC afin de cibler davantage l'argent des contribuables vers la fourniture de biens publics. Notre hypothèse est qu'un transfert de budget des paiements directs vers les paiements environnementaux augmenterait l'adoption volontaire des SE sans nécessiter de financement supplémentaire de la part du contribuable. En utilisant les données françaises du Réseau d'information comptable agricole (RICA), nous simulons l'effet d'un transfert de 7,5% des paiements directs vers les MAEC et le soutien à l'agriculture biologique.

Question de recherche 2 : Un bonus conditionnel pourrait-il renforcer l'engagement des agriculteurs et les inciter à dépasser les seuils écologiques ?

Lorsque l'objectif d'un PSE est la protection de la qualité de l'eau ou la biodiversité, une masse critique et une continuité spatiale des engagements à l'échelle du paysage sont nécessaires pour observer des améliorations environnementales. Des études montrent que les agriculteurs sont réticents lorsque des exigences collectives conditionnent l'ensemble du paiement, mais qu'ils sont plus favorables à un bonus récompensant une action collective en plus d'un paiement individuel (Ben-Othmen and Ostapchuk, 2019; Kuhfuss et al., 2016; Le Coent et al., 2017; Villamayor-Tomas et al., 2019; Villanueva et al., 2017). L'introduction d'une conditionnalité liée à l'approche paysagère sous la forme d'un paiement bonus pour déclencher une plus grande agglomération et un résultat environnemental limite les risques pour un agriculteur de ne recevoir aucune compensation pour ses SE si l'effort et les surfaces agrégés sont insuffisants.

A partir d'une expérience de choix réalisée lors d'enquêtes auprès d'agriculteurs du nord-ouest de la France, le chapitre 3 vise à mesurer les préférences des agriculteurs pour un contrat PSE avec un paiement dont une partie serait conditionnée par le parrainage d'autres agriculteurs sur le territoire éligible (bonus de parrainage) et/ou un résultat environnemental collectif (amélioration de la qualité de l'eau). Deux hypothèses sont sous-jacentes : (i) la prime de parrainage permet de recruter plus d'agriculteurs sur un même territoire et d'augmenter les engagements ES à l'échelle du paysage, et favorise donc la fourniture de biens publics seuils, (ii) l'effet collaboratif de la prime de parrainage peut être renforcé par une récompense collective pour l'atteinte d'un résultat environnemental sur le territoire.

Question de recherche 3 : Quels sont les éléments techniques à prendre en compte pour définir un paiement proportionnel au résultat environnemental ?

Les règles de conditionnalité des PSE à obligation de résultat définissent un paiement basé sur la réalisation d'un résultat environnemental, plutôt que sur la mise en œuvre de pratiques prescrites. En théorie, ils présentent les mécanismes de paiement les plus ciblés sur la fourniture de biens publics. Elle favorise également l'efficacité des agriculteurs, qui sont libres de choisir les pratiques les moins coûteuses adaptées à leur situation pour satisfaire aux exigences contractuelles (Herzon et al., 2018). Des difficultés techniques se posent quant à la manière de capter et de mesurer précisément l'effort environnemental des agriculteurs, et de définir le niveau de paiement (Massfeller et al., 2022; Uthes and Matzdorf, 2013; Zabel and Roe, 2009a).

Sur la base d'un PSE existant à obligation de résultat, le PSE Eco-Méthane (Le Gloux et al., 2021), le chapitre 4 explore l'adoption de pratiques permettant de réduire les émissions de méthane entérique des vaches laitières par la mise en place d'un paiement conditionné aux unités d'équivalents CO₂ atténuées par litre de lait. En particulier, nous étudions l'importance de prendre en compte la place de l'herbe dans l'alimentation du troupeau (i) dans le choix de l'indicateur d'émissions définissant l'unité de paiement, (ii) dans la définition du niveau de paiement par rapport au surcoût d'un changement de régime alimentaire des vaches laitières.

Question de recherche 4 : L'étiquetage sur la fourniture complémentaire de bénéfices privés augmente-t-il l'efficacité des écolabels ?

Pour compléter le financement public limité, il devient important de s'intéresser à la demande en biens publics, notamment d'identifier des outils permettant de capter davantage de CAP. Fournir aux consommateurs des informations sur les SE fournis par les agriculteurs par le biais de l'étiquetage des produits alimentaires leur permet d'exprimer leurs préférences pour l'environnement et d'envoyer un signal prix aux agriculteurs pour encourager les SE. Des études empiriques ont montré que les préoccupations en matière de santé sont souvent les principaux motifs d'achat de produits respectueux de l'environnement (Aldanondo-Ochoa and Almansa-Sáez, 2009; Brécard et al., 2009; Verhoef, 2005).

Dans le cinquième chapitre de la thèse, nous nous intéressons au cas spécifique où la technologie de production jointe est telle que la fourniture de SE est complémentaire à la production d'une denrée agricole fournissant des bénéfices pour la santé. Notre hypothèse est que des contributions plus élevées et la fourniture de SE pourraient être atteintes en fournissant des preuves scientifiques de leurs effets positifs sur la santé aux consommateurs. Nous développons un modèle théorique de pour étudier la fourniture d'un bien public à travers trois labels (label environnemental, label santé, label santé et environnement), et dérivons les conditions d'optimalité en fonction des objectifs d'un planificateur social, d'une agence environnementale ou d'une agence sanitaire.

Chapitre 2. Amplifier les incitations environnementales dans la politique agricole commune : une méthode d'évaluation ex ante appliquée avec le réseau d'information comptable agricole

Dans ce chapitre co-écrit avec Pierre Dupraz, nous évaluons le levier d'un meilleur ciblage du budget public de la PAC vers des instruments de fourniture de biens publics. Les MAEC et le soutien à l'agriculture biologique sont les deux principaux instruments soutenant l'adoption de pratiques agricoles respectueuses de l'environnement dans l'Union Européenne depuis les années 90. Ils ont été insuffisants pour atteindre des améliorations environnementales significatives, notamment parce que sous-financés par rapport aux aides au revenu sans ou avec peu de conditionnalité environnementale (paiements directs).

En utilisant les données du panel français du RICA de 2015-2019, un modèle Tobit généralisé est appliqué pour estimer simultanément la probabilité d'adopter un contrat environnemental et le paiement acceptable déclenchant cette décision pour chaque observation de l'échantillon et pour chaque type de contrat. Nous utilisons un large ensemble de variables de contrôle afin de surmonter le manque d'informations sur le type d'engagements, le montant du paiement par hectare et les surfaces contractualisées des exploitations participantes. Ce modèle d'adoption volontaire est utilisé pour simuler l'adoption des MAEC et du soutien à l'agriculture biologique si les paiements directs étaient diminués de 7,5% et que ce budget était redirigé vers le financement de dispositifs environnementaux en 2019.

Nos résultats montrent que ce mécanisme augmente la participation (de 11% à 24% pour les MAEC, de 7 à 17% pour le soutien à l'agriculture biologique). Ce résultat s'explique par deux incitations combinées favorisant l'adoption. Un effet direct de l'augmentation des fonds publics disponibles permet de financer de nouveaux engagements environnementaux. Un effet indirect d'une diminution des paiements directs tend à réduire les paiements acceptables déclenchant la participation des exploitations, permettant de financer encore plus d'exploitations. L'effet du transfert budgétaire diffère selon la spécialisation de l'exploitation. L'adoption des MAEC par les élevages bovins est favorisée, tandis que les exploitations spécialisées dans les cultures permanentes, l'élevage de granivores et des vaches laitières ont tendance à adopter davantage de soutien à l'agriculture biologique (maintien ou conversion). Une des limites à la généralisation de nos résultats et que les modèles d'adoption estimés ne parviennent pas à saisir suffisamment l'hétérogénéité des exploitations pour reproduire avec précision le comportement observé, en particulier pour les MAEC.

Chapitre 3. Paiements pour services environnementaux en présence de seuils écologiques : préférences des agriculteurs pour un bonus de parrainage

L'une des principales limites des PSE développés depuis le début des années 1990, est leur inefficacité lorsqu'il s'agit d'augmenter la fourniture de biens publics avec des effets de seuil. En particulier, la conditionnalité basée sur des obligations de moyens, qui consiste à prescrire des pratiques agricoles aux agriculteurs individuels sans tenir compte de ce qui est fait dans les exploitations voisines, semble inadéquate pour remédier à leur sous-production. Dans ce chapitre co-écrit avec Pierre Dupraz, Alice Issanchou et Carole Ropars-Collet, nous étudions l'introduction d'un mécanisme de paiement combinant une conditionnalité basée sur des obligations de moyen avec un bonus récompensant une démarche collective.

Au travers d'expérience de choix réalisée auprès de 130 agriculteurs en Bretagne, Normandie et Pays de la Loire, nous proposons un bonus de parrainage en complément d'un paiement individuel à l'hectare pour promouvoir une plus grande participation dans la zone cible d'un PSE. Nous mesurons les préférences ex ante des agriculteurs pour un tel mécanisme de bonus dans un PSE fictif visant à améliorer la qualité de l'eau des rivières. Les 4 attributs du contrat étaient une couverture minimale du sol tout au long de l'année, une densité minimale de haies anti-érosives, un paiement individuel à l'hectare et une option de bonus à trois niveaux : (i) aucun bonus, (ii) un bonus de parrainage de 450€ chaque fois que l'agriculteur convainc un pair d'adopter le PSE, (iii) le bonus de parrainage combiné à un bonus de résultat collectif de 50€/ha distribué à tous les participants si l'état de la rivière atteint un échelon supérieur de l'échelle de qualité de l'eau.

Les résultats suggèrent qu'en moyenne, les répondants préfèrent les contrats avec un bonus de parrainage aux contrats sans bonus. Ceteris paribus, cela correspondant à une réduction du consentement à recevoir de 40€/ha en moyenne pour un contrat avec un bonus de parrainage par rapport à un contrat sans. Les répondants sont en revanche moins favorables à la possibilité de cumuler le bonus de parrainage et le bonus pour le résultat collectif dans un même contrat. Derrière ces résultats se cachent une hétérogénéité des agriculteurs. Une des limites à la généralisation des résultats est le biais d'échantillonnage en faveur de la population déjà la plus susceptible de souscrire un PSE et de mettre en œuvre des SE ambitieux.

Chapitre 4. Prise en compte du régime alimentaire des vaches pour concevoir des paiements pour réduire les émissions de méthane entérique dans les exploitations laitières

Une source d'inefficacité des PSE à obligation de moyens est qu'ils rémunèrent des pratiques sans additionnalité environnementale si les SE demandés ne sont pas assez ambitieux et/ou pas adaptés au bien public visé. Ce chapitre est co-écrit avec Sabine Duvaleix et Pierre Dupraz, et se concentre sur la conception de PSE à obligation de résultat.

Inspirés par une étude de cas française, nous étudions deux éléments de conception des PSE visant la réduction des émissions de méthane entérique dans les exploitations laitières qui sont cruciaux pour leur efficacité : le choix de l'indicateur d'émissions capturant l'effet des pratiques des agriculteurs, et le montant du paiement par rapport aux coûts supplémentaires de production de lait encourus. En utilisant les données publiques du RICA 2016-2018, nous comparons les émissions entériques calculées avec une méthode Tier2 telle que classifiée par le Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC) aux émissions de références de la méthode utilisée dans le PSE Eco-Méthane tenant compte des effets du régime alimentaire. Nous quantifions également les coûts de production laitière supplémentaires liés à l'intégration de plus d'herbe (un des leviers pour réduire les émissions par litre de lait) dans les systèmes fourragers en estimant des fonctions de coûts variables pour différents systèmes laitiers en France selon le bassin de production et le système fourrager.

Nos résultats montrent la pertinence de l'utilisation d'un indicateur d'émissions sensible aux effets du régime alimentaire, en particulier pour ne pas surestimer les émissions des exploitations avec une part importante d'herbe dans leur assolement fourrager. Nos estimations suggèrent que la plupart des exploitations présentent des surcoûts importants et élevés, en particulier les exploitations de plaine avec une part importante de prairies et les exploitations de montagne. Pour soutenir une transition à grande échelle, le niveau de paiement devrait être suffisamment élevé pour dépasser ces coûts, ou modulé en fonction du système laitier. Une des limites à la généralisation de nos résultats est que nous ne caractérisons l'hétérogénéité des coûts supplémentaires des exploitations pour réduire les émissions entériques que pour le levier spécifique de la place de l'herbe dans l'assolement fourrager, sans prendre en compte (par manque de données), des actions complémentaires telles que l'apport de compléments tels que le lin extrudé dans la ration.

Chapitre 5. Comment l'étiquetage santé peut-il améliorer la fourniture de biens publics environnementaux ?

Ce chapitre co-écrit avec Elodie Letort et Pierre Dupraz, s'intéresse à la question de la sous-provision des biens publics environnementaux par le marché. Les PSE inclus dans la chaîne de valeur visent à capter la CAP pour les SE des parties prenantes le long de la chaîne alimentaire, en différenciant les biens produits avec des pratiques respectueuses de l'environnement de ceux produits avec des pratiques dites "conventionnelles" et en introduisant une prime de prix. Contrairement aux systèmes dédiés, les PSE inclus dans la chaîne de valeur peuvent non seulement mobiliser le CAP pour les SE, mais aussi pour le type de denrée agricole produit de manière jointe et toute autre caractéristique attachée à ce produit agricole pour laquelle les consommateurs peuvent avoir des préférences. Par conséquent, le développement de ce canal de paiement représente une opportunité d'obtenir des contributions supplémentaires (indirectes) des consommateurs à la fourniture de SE.

Cette étude se concentre sur le cas particulier où une jointure de production existe entre la fourniture d'un bien public environnemental global et l'amélioration de la qualité nutritive d'une denrée agricole, de manière à ce qu'il prodigue également des bienfaits supérieurs pour la santé par rapport à son substitut conventionnel. Nous adaptons un modèle de bien public impur inspiré de (Kötchen, 2005) pour comparer un label environnemental, un label de santé et un label promouvant à la fois la santé et l'environnement, toujours sous l'hypothèse de cette jointure santé/environnement. Nous modélisons comment le degré d'information sur les caractéristiques publiques et privées fournies aux consommateurs affecte la fourniture de bien public à l'équilibre de marché. Une simulation est effectuée pour illustrer l'impact des préférences des consommateurs sur la fourniture de bien public.

Nous montrons que la fourniture de bien public est plus élevée avec un label de santé qu'avec un label environnemental dans la plupart des situations. L'ampleur de ce résultat dépend des préférences des consommateurs et de la taille du marché. Du point de vue d'un planificateur social, le bien public reste insuffisamment fourni dans tous les contextes de marché. Cependant, sous certaines conditions, un label de santé et un label de santé et d'environnement conduiront à la fourniture optimale du bien public du point de vue d'une agence environnementale. Une des limites à la généralisation de nos résultats est cette hypothèse de jointure forte et linéaire entre pratiques respectueuses de l'environnement et amélioration nutritionnelle de la denrée agricole.

Chapitre 6. Conclusion générale

Dans les approches de modélisation empirique, cette thèse étudie les PSE en considérant différentes échelles : l'échelle de la politique globale au chapitre 2, l'échelle du contrat au chapitre 3 et l'échelle de la conception du paiement au chapitre 4. Cette approche multi-échelle permet d'obtenir une image plus large des différents facteurs de l'efficacité environnementale des PSE et de leurs limites, chacun d'entre eux fournissant des informations sur le signal incitatif envoyé aux agriculteurs.

Les résultats suggèrent qu'à l'échelle des politiques publiques, l'efficacité des PSE peut être améliorée en ciblant davantage le budget vers des instruments de fourniture de biens publics. À l'échelle de la conception du PSE, l'introduction de nouveaux mécanismes de conditionnalité des paiements, tels que des incitations collectives et/ou axées sur les résultats, adaptés au bien public visé, devrait favoriser l'obtention de résultats environnementaux, à condition qu'ils soient acceptés et largement adoptés par les agriculteurs. Par conséquent, l'amélioration de la conception des PSE va de pair avec la garantie que le niveau de paiement dépasse le consentement à recevoir des agriculteurs. Le fait d'autoriser les contributions d'une diversité de contributeurs avec un CAP peut aider à réunir un budget suffisant. Les trois approches empiriques contribuent également à caractériser l'hétérogénéité des systèmes agricoles en particulier en ce qui concerne la rentabilité de l'adoption des PSE (chapitre 2), l'acceptabilité des attributs du contrat (chapitre 3) et les surcoûts liés au changement de pratiques (chapitre 4). De plus, nos résultats théoriques (chapitre 5) montrent que lorsqu'il est possible d'identifier des avantages privés à la fourniture de SE, les PSE inclus dans la chaîne de valeur peuvent être des instruments efficaces pour compléter les politiques agro-environnementales. Des études scientifiques visant à comprendre l'étendue et la diversité des technologies de production jointes permettraient d'identifier les cas où cela ce levier pourrait s'appliquer.

Les résultats empiriques des chapitres 2 et 4 sont dérivés d'analyses du RICA, qui contient peu d'informations permettant de caractériser précisément les pratiques agricoles et les SE mis en œuvre au niveau de l'exploitation. Pour établir un lien entre l'adoption d'un PSE et les changements de pratiques agricoles et les résultats environnementaux, il a fallu formuler des hypothèses (fortes). L'initiative et la feuille de route de la Commission européenne pour la conversion du RICA en Réseau de données sur le développement durable des exploitations agricoles (FSDN) faciliteront la modélisation des changements de pratiques des agriculteurs à l'avenir (EC, 2022a).

Contents

Remerciements	i
Funding.....	iii
Synthèse	iv
Contents.....	xvi
List of tables	xix
List of figures	xxi
List of abbreviations.....	xxii
CHAPTER 1. GENERAL INTRODUCTION.....	1
1.1. Background.....	5
1.1.1. Characteristics of agri-environment-climate public goods	5
1.1.2. Characteristics of agri-environment-climate public good supply	7
1.1.3. Characteristics of agri-environment-climate public good demand	9
1.1.4. Payments for environmental services.....	10
1.2. Review of existing PES in the EU and identification of inefficiency issues	11
1.2.1. Agri-environmental (-climatic) measures under the CAP.....	12
1.2.2. Diversity of payment for environmental services financing mechanisms	15
1.2.3. Diversity of payment for environmental services payment mechanisms.....	19
1.3. Problem statement, objective and research questions	22
1.4. Outline of the PhD thesis.....	28
CHAPTER 2. UPSCALING ENVIRONMENTAL INCENTIVES IN THE COMMON AGRICULTURAL POLICY: AN EX-ANTE EVALUATION METHOD APPLIED WITH THE FARM ACCOUNTANCY DATA NETWORK.....	29
2.1. Introduction	30
2.2. Materials and methods.....	33
2.2.1. Theoretical model of voluntary adoption of an environmental contract.....	33
2.2.2. Econometric model of voluntary adoption of an environmental contract	34
2.2.3. Data	35
2.2.4. Simulation of CAP budget transfer.....	40
2.3. Estimated model of AECM and OFS uptake.....	41
2.4. Results of the simulation.....	49
2.5. Discussion and concluding remarks	52

CHAPTER 3. PAYMENTS FOR ENVIRONMENTAL SERVICES WITH ECOLOGICAL THRESHOLDS: FARMERS' PREFERENCES FOR A SPONSORSHIP BONUS	54
3.1. Introduction	56
3.2. Method.....	59
3.2.1. Discrete choice experiment approach	59
3.2.2. Model specification.....	59
3.2.3. Experimental design.....	61
3.2.4. Survey structure	65
3.3. Data.....	66
3.4. Results	69
3.5. Concluding remarks.....	74
CHAPTER 4. TAKING THE DIET OF COWS INTO CONSIDERATION IN DESIGNING A PAYMENT TO REDUCE ENTERIC METHANE EMISSIONS ON DAIRY FARMS	77
4.1. Introduction	79
4.2. Background on enteric methane emission indicators	80
4.3. A Tier 3 indicator applied in the Eco-Methane result-based scheme.....	81
4.4. Materials and methods.....	83
4.4.1. Data	83
4.4.2. Attribution of enteric methane emissions	84
4.4.3. Estimation of the extra-cost of milk production with more grass in the fodder system	86
4.5. Results and discussion.....	90
4.5.1. Allocation of Eco-Methane scenarios and distinction of three milk production basins	90
4.5.2. Enteric emissions: relation to productivity and fodder system.....	91
4.5.3. Impact of increasing the grassland area on the marginal cost of milk production .	95
4.6. Conclusions	98
CHAPTER 5. HOW CAN LABELING FOR HEALTH CONCERNS IMPROVE ENVIRONMENTAL PUBLIC GOOD PROVISIONING?	99
5.1. Introduction	101
5.2. Preliminaries	102
5.3. Optimal regulation of our economy	105

5.3.1. Social optimum	105
5.3.2. Environmental agency's optimum	106
5.3.3. Health agency's optimum	107
5.4. Equilibria under different levels of information	108
5.4.1. Health and environment label	108
5.4.2. Environment label	109
5.4.3. Health label	110
5.5. Comparison of public good provision.....	111
5.5.1. Public good demand function	111
5.5.2. Simulations of different market equilibria.....	114
5.6. Conclusion.....	117
CHAPTER 6. GENERAL CONCLUSION	120
6.1. Main contributions.....	121
6.2. Main limits	125
Appendices	129
Appendix A1. Farm Accountancy Data Network sample coverage of farms with organic practices	130
Appendix A2. Descriptive statistics of the Farm Accountancy Data Network sample ..	131
Appendix A3. Coefficients of the generalised Tobit models.....	134
Appendix A4. Choice experiment survey	137
Appendix A5. Attribution of Eco-Methane scenarios to the French regions	180
Appendix A6. Instrumentation of grass fodder area and milk production in the estimation of milk production costs.....	182
Appendix A7. Estimates of milk production cost and input cost share functions of French dairy systems.....	183
Appendix A8. Assumptions on the production technology of differentiated goods.....	189
Bibliography.....	190

List of tables

Table 1.1. Ambitions and instruments accompanying the agricultural sector for the delivery of water quality, biodiversity and climate targets in the European Union.	4
Table 1.2. Payments for environmental services mechanisms to allocate the willingness to pay of contributors in France.	18
Table 2.1. Common Agricultural Policy budget and beneficiaries in 2015-2019.	37
Table 2.2. Descriptive statistics of the sample (N=28,967).	40
Table 2.3. Comparison between observed and estimated adoption behaviour (N=28,967). ...	42
Table 2.4. Generalised Tobit models estimation: marginal effects at the sample mean.	43
Table 2.5. Simulated impact of a decrease of 7.5% of direct payments in 2019 (N=7,194)...	49
Table 2.6. Change of allocation of environmental incentives among farm types with an additional transfer of 7.5% of direct payments budget to reach 15% in 2019 (%) (N=7,194). 51	
Table 2.7. Impact of a budget transfer in 2019 under several transfer scenarios (N=7,194). .	52
Table 3.1. Attributes and attribute levels in the choice experiment.	62
Table 3.2. Descriptive statistics of the sample (N=130).	67
Table 3.3. Conditional Logit estimations.	69
Table 3.4. Mixed Logit estimations (normal distribution of random parameters).	71
Table 3.5. Marginal willingness to accept the payment for environmental services contract design characteristics, estimated with the delta method (€/ha/year).	72
Table 3.6. Selection of Latent Class model.	73
Table 3.7. Latent Class estimation.	74
Table 4.1. Description of the sample (N=2,205)	84
Table 4.2. Characteristics of the eleven baseline scenarios used in the Eco-Methane scheme	85
Table 4.3. Mean values of the model variables	89
Table 4.4. Average enteric emissions of the sample according to the TIER2 and Eco-Methane baseline indicators.	92
Table 4.5. Extra-costs of milk production with an increase in grassland area	96
Table 5.1. Different market settings compared in the paper.	104
Table A1.1. Sample coverage of farms with organic practices in 2019	130
Table A2.1. Education level of the farms of the sample	131
Table A2.2. Regions of the farms of the sample	132
Table A2.3. Technical orientations of the farms of the sample.	133

Table A3.1. Estimates of the generalised Tobit models for the uptake of agri-environment-climate measures and organic farming support.....	134
Table A5.1 Eco-Methane scenarios attribution to the French regions	180
Table A7.1. Result of the system estimation for France (N=2,205).....	183
Table A7.2. Result of the system estimation for the plains of the western region (N=645) .	184
Table A7.3. Result of the system estimation for the plains outside the western region (N=975)	185
Table A7.4. Result of the system estimation for the mountainous areas (N=585).....	186
Table A7.5. Result of the system estimation for plains with more than 30% of corn in the fodder area (N=767)	187
Table A7.6. Result of the system estimation for plains with less than 30% of corn in the fodder area (N=853)	188

List of figures

Figure S.1. Mécanismes de paiements pour services environnementaux pour remédier à la sous-provision des biens publics par l'agriculture	vii
Figure 1.1. Main interactions between agroecosystems and the environment.	2
Figure 1.2. The logic of payments for environmental services for securing land use conservation.	11
Figure 1.3. Payments for environmental services mechanisms to tackle the underprovision of public goods by agriculture.	24
Figure 3.1. Example of choice set of the choice experiment.....	64
Figure 3.2. Distribution of the sampled farms in the surveyed regions (ratio).	66
Figure 3.3. Stated effect of contract design characteristics on willingness to adopt.....	68
Figure 4.1. Distribution of Eco-Methane baseline scenarios among French regions.....	91
Figure 4.2. Average enteric emissions in French regions according to the TIER2 and Eco-Methane baseline indicators.	93
Figure 5.1. Simulation of public good provisions.	115

List of abbreviations

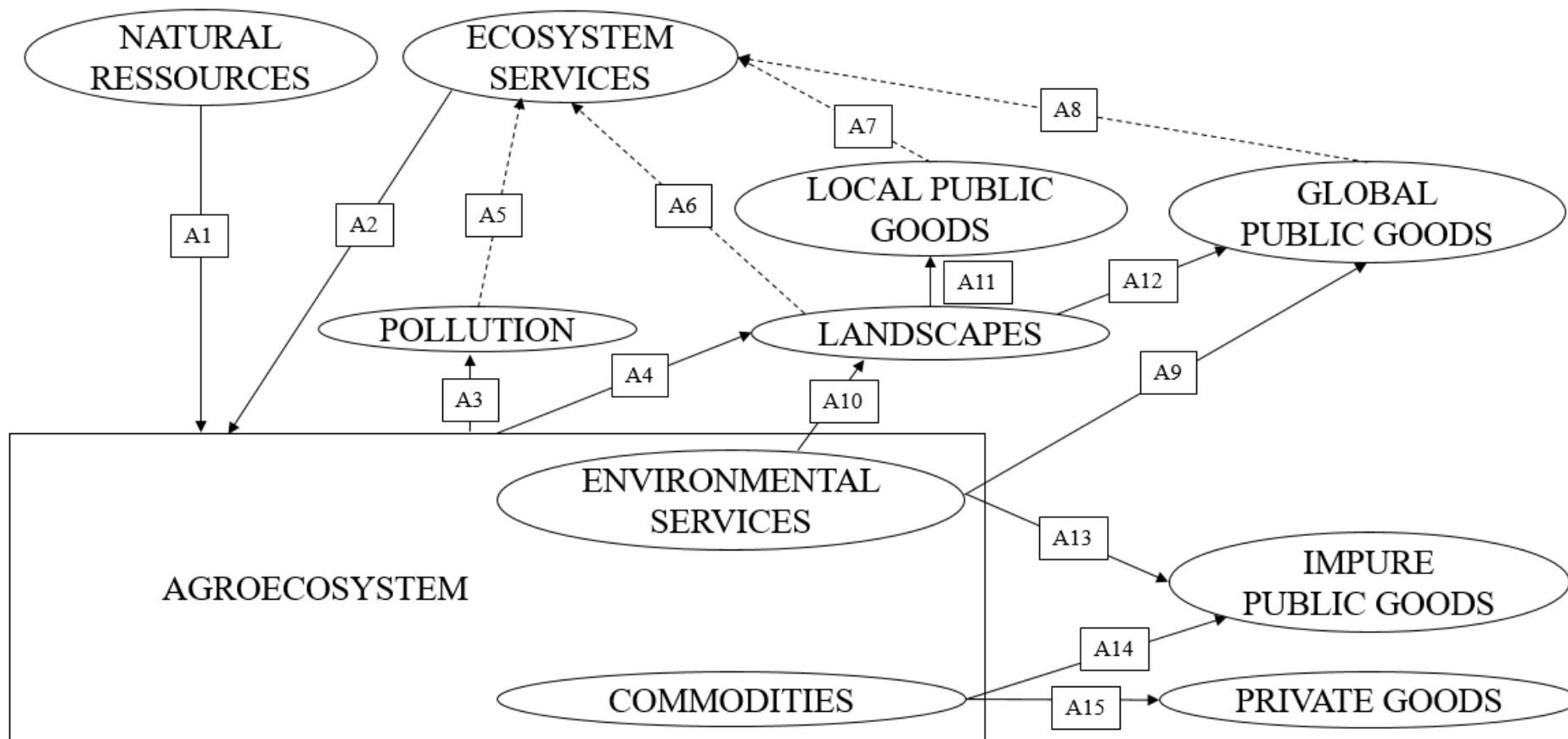
AECM	Agri-Environment-Climate Measure
CAP	Common Agricultural Policy
CE	Choice Experiment
EC	European Commission
EEA	European Environmental Agency
ES	Environmental Services
EU	European Union
FADN	Farm Accountancy Data Network
GHG	Greenhouse Gas
OFS	Organic farming support
PES	Payments for Environmental Services
UAA	Utilised Agricultural Area

Chapter 1. General introduction

Farming is intrinsically connected to natural resources and ecosystems. To produce food, agricultural activities remove resources (water, land) from natural ecosystems and biophysical processes, and use inputs derived from natural resource extraction (metals, fossil fuels) (arrow A1 in figure 1.1). Farming also benefits from supporting (photosynthesis, nutrients and water cycling, soil formation and fertility, genetic biodiversity) and regulating (pollination, disease and pest control, water purification, decomposition, climate) ecosystem services (arrow A2 in figure 1.1). In addition, agriculture contributes to shaping landscapes and modifying natural habitats, and releases greenhouse gases (GHG), chemicals and nutrients into the environment (water, air, soil) (arrows A3-A4 in figure 1.1) (Heal and Small, 2002; Lichtenberg, 2002; Millennium Ecosystem Assessment, 2005; Therond et al., 2017).

Those carbon, nitrogen, phosphorus and water cycle disruptions affect climate and habitats with pollution and increased vulnerability to natural hazards (arrows A5-A6 in figure 1.1) (Abu Hatab et al., 2022; Bezner Kerr et al., 2022; EEA, 2019). In Europe, the agricultural sector is the second contributor to GHG emissions (EEA, 2022), the first contributor to diffuse water pollution (EEA, 2021), and often the main source of pressure on habitats and species (EEA, 2020a; IPBES, 2019). In return, both short and long-term effects of ecosystem degradation and climate change affect agricultural production capacities (Bezner Kerr et al., 2022).

The multiple interactions between farming activities and natural ecosystems make the agricultural sector both a producer of food commodities and a provider of public goods (and bads), for which the benefits (and damages) are available and accessible to many beyond the farm gates (Cooper et al., 2009). Public goods include habitats for a diversity of species (farmland flora and fauna), long-term storage of carbon in soils and landscape features, and the protection of river catchments' soil and water quality (arrows A7-A8 in figure 1.1). Since the rise of global environmental concerns in the 1970s, scientists have built extensive knowledge of the interactions between farm systems and the environment, and on farmers' practices mitigating pressures on ecosystems (Altieri, 1995; Bezner Kerr et al., 2022). With environmental concerns and solutions well identified, the challenge today is to upscale their adoption and to finance the transition.



Plain arrows: direct interactions. Dotted arrows: indirect interactions.

Source: own elaboration.

Figure 1.1. Main interactions between agroecosystems and the environment.

The European Commission (EC) defines ambitious strategies and targets for 2030 and 2050 regarding water, air and soil quality, biodiversity and climate. Some derive from binding international agreements such as the Convention on Biological Diversity and the Paris Agreement (United Nations, 2015, 1992), or are cross-cutting with global Sustainable Development Goals (EC, 2022b). The Climate Law commits the EU to reach net zero GHG emissions by 2050 (EU, 2021). The EC recently published a proposal for a Nature Restoration Law with binding obligations (EC, 2022c). The Farm to Fork Strategy and the Biodiversity Strategy for 2030 include quantified targets: a reduction by 50% of chemical pesticides use and risk, antimicrobials sales and nutrient losses, together with a reduction by 20% of fertilizer use. In addition, the EC aims at 25% of agricultural land under organic farming by 2030 (EC, 2020a, 2020b). To meet these targets, one can build on existing regulations (ex: Directives) defining baseline standards of agricultural practices and protected areas for biodiversity since the 1970s. They are the legal requirements farmers must comply with. In addition, incentive tools can be developed. The latter has been introduced in some of the Common Agricultural Policy (CAP) instruments since the 1990s (Table 1.1). In particular, the CAP offers support payments to farmers adopting environment-friendly practices, including organic farming, beyond legal requirements and standards of good practices (Council of the European Communities, 1992a). In addition, part of the direct payments per hectare farmers receive as income support depends on crop diversification and maintaining permanent grasslands and ecological focus areas since 2013 (EU, 2013a). So far, the regulations and the CAP have been insufficient in securing the delivery of the climate, biodiversity and water quality targets (Table 1.1).

Payment for environmental services (PES) are instruments providing a financial incentive for farmers to adopt more environment-friendly practices. They recognise farmers' voluntary activities and interventions contributing to public goods as environmental services (ES), for which they can receive a payment. PES schemes introduce financing mechanisms to capture the willingness to pay for ES on the one hand, and payment mechanisms to encourage farmers to provide ES on the other hand (Pagiola and Platais, 2002). PES are tools for meeting the supply and demand of agri-environment-climate public goods and aim at accompanying a large-scale agroecological transition towards reaching better provision by the agricultural sector.

Table 1.1. Instruments accompanying the agricultural sector for the delivery of water quality, biodiversity and climate targets in the EU.

Political objective	Current instruments	Delivery state
Maintain bird species populations naturally occurring in the EU at a level corresponding to ecological requirements (79/409/EEC). Put biodiversity on a path to recovery by 2030 (COM(2022)304). All ecosystems are restored, resilient, and adequately protected by 2050 (COM(2022)304).	Birds Directive (79/409/EEC, 2009/147/EC): Special Protection Areas, Species Action Plans. Habitats Directive (92/43/EEC): Natura 2000 network. CAP (EEC/2078/92, EC/73/2009, EU/1307/2013): incentives for voluntary low-intensity practices and maintenance of areas for nature and habitats, requirements of retention of landscape features.	Farmland birds population trend (2020): 18% increasing, 21% stable, 54% decreasing. Good conservation status (2020): 30% farmland species, 12% agricultural habitats.
Surface water and groundwater bodies must achieve good chemical and ecological status by 2027 (2000/60/EC). Zero pollution for water for 2050 (COM(2021)400).	Groundwater Directive (80/68/EEC): prohibition and limitation of dangerous substances discharge. Sewage sludge Directive (86/278/EEC): limitation of sewage sludge composition and use. Nitrates Directive (91/676/EEC): Nitrates Vulnerable Zones. Sustainable Use of Pesticides Directive (2009/128/EC): National Action Plans. Water Framework Directive (2000/60/EC): measures for each river basin district. CAP (EEC/2078/92, EC/73/2009, EU/1307/2013): incentives for voluntary sustainable input management practices, requirement of buffer strips along watercourses.	Good ecological status (2021): 44% (surface water). Good chemical status (2021): 31% (surface water), 75% (groundwater).
Reduce net GHG emissions by 55% 1990 by 2030 (EU/2021/1119). Net zero emissions by 2050 (EU/2021/1119). Keep global temperature increase below 2°C above pre-industrial levels by 2100 (UN Treaty).	CAP (EU/1305/2013, EU/1306/2013, EU/1307/2013): incentives for voluntary carbon storage, sustainable fertiliser and manure management practices, requirement of minimum soil cover. Climate Law (EU/2021/1119).	Agricultural GHG (2022): -20% 2020 1990. Stagnation since 2010. Emissions from livestock, manure and fertilisation increased.

EU: European Union. GHG: greenhouse gas. UN: United Nations. CAP: Common Agricultural Policy.

Source: own elaboration, using data and information from (Commission of the European Communities, 1996; Council of the EU, 2009; Council of the European Communities, 1979, 1986, 1991, 1992b, 1992a; EC, 2021a; EEA, 2020a, 2021, 2022; EU, 2000, 2009, 2010, 2013a, 2013b, 2013c, 2021; European Court of Auditors, 2021; United Nations, 2015).

In this introductory chapter, I present the main concepts and definitions around PES and provide a short literature review of the different types of PES mechanisms implemented in the European Union (EU). The review identifies some of the efficiency issues of current PES and which mechanisms could be implemented to overcome them. I then present the way I apprehend PES, and the research questions I develop throughout my PhD thesis.

1.1. Background

1.1.1. Characteristics of agri-environment-climate public goods

The public benefits provided by agriculture exhibit the intrinsic characteristics of public goods. The utility individuals derive from their provision is interdependent (Marmolo, 1999).

The first axis for which one can differentiate public goods from other types of goods is that the consumption of one unit by an individual does not affect the consumption opportunities of other individuals of that same unit of good (Samuelson, 1954). This characteristic is referred to as non-rivalry of consumption or indivisibility of benefits (Cornes and Sandler, 1986). A second axis differentiates the nature of goods according to whether some individuals can be excluded from the possibility of consumption. Excludability distinguishes two categories of goods with non-rivalry: non-excludable pure public goods and excludable club goods (Sandler and Tschirhart, 1997). With complete non-excludability, consumption is mandatory for all individuals, while full excludability distinguishes a population with access to non-rival consumption and a population with no access to it (Cornes and Sandler, 1986).

Typically, climate stability and biodiversity conservation to which agriculture contributes are pure public goods. Individuals enjoy the same level of availability (joint consumption), and cannot be prevented from accessing those benefits. Moreover, they are pure public goods at the global level (global public goods), as benefits have no geographical limit (Stiglitz, 2017). Some other public goods provided by agriculture are closer to club goods. It is the case of water quality or farmland landscape aesthetics, for which the distance to the provision site is a barrier excluding some individuals from its benefits (local public goods) (Cooper et al., 2009).

The special characteristics of public goods make them unlikely to be sufficiently provided through a competitive market. As demonstrated by Samuelson (1954), non-rivalry makes the conditions for the optimal provision of public goods to differ from private goods. Let us consider the objective function (1.1) of a social planner who wishes to determine the optimal amount of a public good Y maximising the social welfare of I individuals. Each individual i exhibits a utility functions $U^i(X^i, Y)$ depending on the consumption level of a private good X and benefits from the level of public good Y . The economy is constrained by its production possibility representing how the production of X and the provision of Y are related (transformation function F).

$$\max_Y W[U^1(X^1, Y), \dots, U^N(X^N, Y)] \text{ s. t } F(\sum_{i=1}^N X^i, Y) = 0 \quad (1.1)$$

The first-order-conditions gives the Bowen-Lindahl-Samuelson (BLS) condition:

$$\alpha^N = \sum_{i=1}^N \frac{\frac{\partial U^i}{\partial Y}}{\frac{\partial U^i}{\partial X^i}} = \frac{\frac{\partial F}{\partial Y}}{\frac{\partial F}{\partial X}} \quad (1.2)$$

At optimal provision, the marginal social benefit of providing the public good equals the sum of the marginal benefits received by all individuals, or the sum of the marginal rates of substitutions between the public good and the private good of all agents equals the marginal rate of transformation between the private and public goods. The economic theory identifies several reasons why intervention is required to meet equation (1.2) (Tietenberg and Lewis, 2018). First, free access (absence of clear property rights) leads to the absence of the formation of a price through a competitive market (missing market). Second, the financing of public good provision suffers from free-riding. Unless constrained by a mandatory contribution, any individual i voluntarily financing public good provision has the incentive to pay up to his or her marginal utility derived from Y , $\frac{\partial U^i}{\partial Y}$, which is less than the optimal amount α^N as soon as

$N \geq 2$. Hence, even if a market exists, the public good is underprovided.

To correct market failures, one needs to know the benefits and costs of public good provision and develops mechanisms to send a price signal to public good providers (farmers) and contributors aiming at satisfying equation (1.2). It requires understanding the supply and demand of agri-environment-climate public goods.

1.1.2. Characteristics of agri-environment-climate public good supply

Before the introduction of a correcting mechanism, the supply of public goods by agricultural activities is an externality associated with food production. An externality arises when “the effect of production [...] imposes costs or benefits on others which are not reflected in the prices” (OECD, 2003). Typically, a farmer does not bear all the costs of pollution damages from farming activities, nor all the benefits of their amenities (Coase, 1960; Tietenberg and Lewis, 2018). The impacts of off-site (outside the farm gate) pollution and public benefits are not necessarily integrated into farmers’ decisions. Sending a price signal supposes to translate public good provision in a way that it can be internalised by the producer. One way is to characterise and recognise the interactions between on-site farming practices and offsite public good provision.

Environmental services (ES) refer to human interventions contributing to the preservation of ecological functions (maintaining or developing ecosystem services) (Duval et al., 2016). According to the analytical framework of Puydarrieux (2014), ES are different from ecosystem services. Contrary to ecosystem services provided by natural ecosystems or biophysical processes without human interventions, ES are provided by humans. ES can be marginal changes in management practices, while ecosystem services are by nature integrated and systemic (Wunder, 2005). Moreover, while some ecosystem services (provisioning services) can directly be charged by suppliers in competitive markets, the notion of ES applies to externalities (FAO, 2007; Sven Wunder, 2015). ES are related, but also different from public goods. One can differentiate ES provided by farmers, and the offsite benefits they contribute to. Those offsite benefits are the agri-environment-climate public goods from which individuals derive utility. In simple terms, ES represent the supply by farmers, while public goods are what society ultimately demands.

The contribution of ES to public good provision is based on biological processes that are often spatially dependent and characterized by threshold effects (Dupraz et al., 2009; Zavalloni et al., 2019). This “transformation” depends on many factors: the type of ES itself and the intensity of environmental effort it represents, the continuity of ES in time and space, and more generally on external drivers (climate, natural conditions...) (Alston et al., 2013; Dupraz et al., 2009). Dupraz et al. (2009) define a transformation function f such that:

$$Y = f(\sum_{j=1}^J s^j, e) \tag{1.3}$$

With Y the offsite environmental benefit (public good provision), s^j the surface dedicated to ES by farmer j and e the environmental effort of the ES.

The existence or absence of threshold effects is linked to the concept of separability of public good provision. Public goods with a high degree of separability can be easily and efficiently provided by isolated farmers while the level of public good provision with a low degree of separability is strongly dependent on the practices of other farmers (Falconer, 2002; Franks, 2011). Examples of a high degree of separability are carbon storage or sequestration, and GES emissions reduction contributing to climate change mitigation (Alston et al., 2013). When a farmer converts arable land to permanent grasslands or any other practice increasing the organic matter content of his or her soil, it directly contributes to climate change mitigation (arrow A9 in figure 1.1). In these cases, there is the near-linear relationship between ES and public good provision with regards to the surface dedicated to ES and effort (f is simply positive and increasing in s^j and e). Water quality and biodiversity are however characterised by ecological threshold effects and a nonlinear relationship with ES provision. A farmer can implement practices to reduce pesticide leaching or nutrients runoff of land, but water quality gains are only observed if ES are continuously implemented on a large share of the upstream watershed over a sufficient period (arrows A10-A11 in figure 1.1) (Landell-mills and Porras, 2002). Similarly, when a farmer maintains set aside areas and hedgerows, biodiversity gains are spatially limited and will depend on complex landscape arrangements and the existence of ecological corridors, as well as continuous effort over time (arrows A10 and A12 in figure 1.1) (Alston et al., 2013). For those public goods, Dupraz et al. (2009) consider there is a critical effort e_0 and a critical cumulated area S_0 below which $Y = 0$.

In the microeconomic literature on agricultural production, ES are considered as a non-commodity output of the farm joint to the production of food commodities (Shumway et al., 1984; Vatn et al., 2002). There is jointness in production when ‘a firm produced two or more outputs that are interlinked so that an increase or decrease of the supply of one output affects the levels of the others’ (OECD, 2001). For instance, some ES contributing to protecting water quality involves reducing nutrients and pesticide use, and can compete with crop yields (Romstad et al., 2000). Grassland biodiversity tends to be complementary to grass-fed livestock products, at least over a certain range of production intensity (Havlík et al., 2005). Moreover, when ES involve putting some land out of production (ex: landscape features such as flower

strips or hedgerows), their provision can compete with food production. Dedicating land to ES activities reduces the amount available for producing food (Havlík et al., 2005; OECD, 2001).

The type of jointness defines whether joint production of agricultural commodities and ES can be implemented with or without additional costs for the farmer. In many cases, ES provision implies extra production costs, in particular opportunity costs (Van Huylenbroeck et al., 2007). Opportunity costs are defined as the “net benefit forgone because the resources providing the service can no longer be used in their next most beneficial use” (Tietenberg, 2003). As a result, market-led or policy-driven price signals affecting the production of food will affect ES provision and vice versa (OECD, 2001).

1.1.3. Characteristics of agri-environment-climate public good demand

Demand for agri-environment-climate public goods can arise from multiple sources and from local to global levels (Madureira et al., 2013).

First, this demand can arise from citizens expressing their environmental preferences, for instance when voting. In this case, securing public good provision is delegated to a government, on behalf of the citizens (centralised demand at the national or local level) (Samuelson, 1954; Tiebout, 1956). Second, there can be demand arising from voluntary initiatives of economic agents with diverse environmental preferences. These decentralised demands take the form of organisations willing to finance ES on behalf of citizens or interest groups, or individual or sectorial environment-friendly ventures following private interests (Besley and Ghatak, 2007; Gosal et al., 2020). Third, customers with environmental preferences also express demand directly to farmers when purchasing food products produced jointly with ES. In the latter case, the expression of this demand depends on the information on joint production made available to consumers. To differentiate a food commodity produced with an environment-friendly production technology jointly providing ES from a conventional food substitute, microeconomic models of consumption consider it an impure public good (Kötchen, 2005). An impure public good exhibits both a private characteristic (food) and a public characteristic (ES provision) affecting the utility of consumers (arrows A13-A15 in figure 1.1) (Cornes and Sandler, 1994).

1.1.4. Payments for environmental services

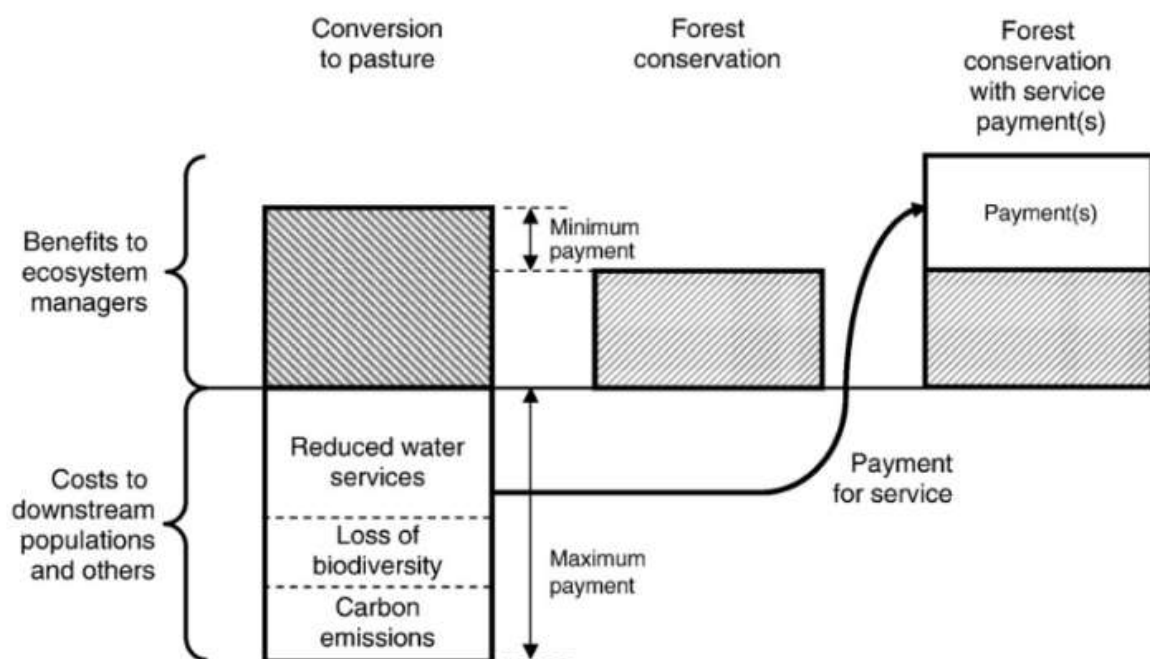
Different instruments correct environmental externalities, from command and control measures to incentives ranging from Pigouvian taxation to Coasian private bargaining (Vatn, 2010). In particular, Coase (1960) suggests that under certain conditions, a contractual solution between the parties involved can efficiently solve a problem of externality (Coase, 1960). PES aim to put into practice the Coasian solution by issuing property rights to farmers for their provision of environmental services (Engel et al., 2008). They are part of the family of positive environmental incentives, based on the beneficiary-pays rather than the polluter-pays principle (Engel et al., 2008; Wunder, 2005). In particular, PES aims at meeting the demand and supply of agri-environment-climate public goods.

Wunder (2015) defines PES as “voluntary transactions between service users and service providers that are conditional on agreed rules of natural resource management for generating offsite services”. The most innovative feature of PES is the conditionality principle, making sure that the ES is delivered. It differentiates PES from subsidies. In many cases, the transaction involves an intermediary acting on behalf of (voluntary) service beneficiaries.

The literature gave rise to several alternative definitions. Some are very close to Wunder’s (FAO, 2007; Karsenty, 2011), while others add new conditions for PES qualification, such as environmental additionality (Duval et al., 2016; Tacconi, 2012). Additionality implies that the introduction of a PES leads to an observed improvement of public good provision compared with a scenario without a defined baseline (Duval et al., 2016).

The aim of introducing a PES is to make privately unprofitable but socially desirable practices become profitable to farmers (Engel et al., 2008). A PES can only be implemented if the willingness to pay (WTP) of the transacting party(ies) paying for the service is higher than the willingness to accept (WTA) of the farmer(s), otherwise maintaining socially-undesirable practices would remain the most profitable option for farmers (Engel et al., 2008). The voluntary participation of the provider is an important criterion to reach an efficient outcome and gives the possibility to farmers who would be worse-off to opt out or renegotiate (Engel et al., 2008; Tacconi, 2012). In theory, the payment should be set between the WTA and the WTP (Alston et al., 2013) (Figure 1.2.). The WTP of a scheme financier is the value she or he attaches to the ES, and depends in particular on the level of underprovision and scarcity of the agri-environment-climate public good it contributes to (Engel et al., 2008; Wunder, 2005). The

WTA of a farmer is made of several components including opportunity costs, transaction costs, fixed costs, environmental awareness...(Duval et al., 2016). Depending on the conditionality rules of the PES, it can also include a risk premium for not meeting requirements despite high efforts (Zabel and Roe, 2009b). Due to jointness in production, ES provision often involves trade-offs with food production, and the PES should compensate for that (Alston et al., 2013; Wunder, 2005). The WTP should cover both the WTA of farmers and PES transaction costs (negotiation, monitoring, enforcement) (Alston et al., 2013).



Source: (Engel et al., 2008).

Figure 1.2. The logic of payments for environmental services for securing land use conservation.

1.2. Review of existing PES in the EU and identification of inefficiency issues

In the next section, I review some existing PES in the EU, aiming at matching the supply and demand for public good provision by agriculture. To identify PES schemes from the literature, I use Wunder 2015's definition with the following adaptation to my research topic:

- 1) A transaction
- 2) Aiming at generating identified offsite services (agri-environment-climate public goods)

- 3) Between service users (that I call contributors)
- 4) To voluntary service providers (farmers)
- 5) Conditional on agreed rules

Similarly to Wunder, I do not add additionality as a condition. According to Wunder (2015), a PES definition must remain “robust to intertemporal variations in implementation”. Additionality means the successful provision of public goods by the PES, and can only be observed ex-post. Nevertheless, securing additionality is crucial for environmental effectiveness (Tacconi, 2012). In addition, Duval et al. (2016) consider that a PES must create an incentive and the payment amount should go beyond compensation for the extra-costs of ES provision. As such a criterion rules out most of the existing public PES, I do not include it.

In the literature, one can alternatively read payment for environmental services and payment for ecosystem services. In reviewing the literature, I considered payment for ecosystem services as a synonym for payment for environmental services. However, following Puydarrieux (2014) and Duval et al. (2016), I systematically use the term environmental services to clarify that I refer to payments associated with human interventions and avoid any confusion.

I start my review by focusing on the main PES currently implemented in EU countries: the agri-environment-climate measures (AECM). I summarise the main limits making them inefficient PES. I then characterise other types of PES that could allow for better matching of social demand and farmers’ supply of agri-environment-climate public goods.

Pagiola and Platais (2002) distinguish two parts in a PES mechanism: the financing mechanism, which is how money is collected from contributors, and the payment mechanism, which is how the money is distributed to service providers. In reviewing the literature, I paid attention to these two dimensions in particular. Overall, the PES mechanism describes how the transmission of the payment is channelled, flows from contributors to farmers, and becomes a price signal.

1.2.1. Agri-environmental (-climatic) measures under the CAP

Since the major reforms of 1992, the CAP of the EU has dedicated parts of its funds to dealing with environmental issues through an agri-environmental policy (Duval et al., 2016). Agri-environmental measures, agri-environment-climate measures since 2014 (AECM), are defined as “incentive-based instruments [...] that provide payments to farmers for voluntary

environmental commitments related to preserving and enhancing the environment and maintaining the cultural landscape” (EU, 2013c; Uthes and Matzdorf, 2013). AECM are a type of PES governed by public law (Duval et al., 2016).

To participate, a farmer must voluntarily commit to change or maintain some agricultural practices for a period of 5 to 7 years (EU, 2005). In exchange, he or she receives an annual payment per unit of element engaged in the contract (surface, linear or point feature...). AECM are co-funded by the European Agricultural Fund for Rural Development on the one hand, and by Member States and local institutions on the other hand. Therefore, the ES financiers are mostly taxpayers at the European and local levels. Following the subsidiarity principle, the Member States determine the geographical scale, the set of technical requirements for eligibility and the payment levels of AECM contracts (EU, 2013c).

The literature shows that the policy has had unsatisfactory results with regards to its objectives and expectations. Generally, but particularly in the areas with important public good underprovision, the participation rate in AECM is too low (Desjeux et al., 2011; Duval et al., 2016). In 2020, only 13% (excluding support to organic farming) of the EU utilised agricultural area (UAA) was under an AECM contract (EC, 2020c). The conditions (participation and effort) to reach ES provision thresholds and observe positive effects on the environment are therefore not met (Zavalloni et al., 2019).

Payments are based on farmers’ average forgone profits (opportunity costs) compared with local references of usual good farming practices for the considered geographical zone, and a small part of the private transaction costs for implementing AECM (Dupraz and Pech, 2007). They do not consider the variability of opportunity costs among farms, nor the uncertainties (prices volatility, yield variability). Moreover, most of the transaction costs such as social and human capital costs are not covered (Duval et al., 2016). Yet, the lack of know-how and transaction costs are an important adoption barrier (Espinosa-Goded et al., 2013).

Hence, one main factor of low participation in AECM is that the payment is a compensation, rather than an incentive, and the amount offered is below the WTA of most farms (Duval et al., 2016). Farmers with low opportunity and compliance costs are more likely to participate (Cullen et al., 2018; Zimmermann and Britz, 2016). In addition, bigger farms are advantaged as they can make economies of scale with transaction costs (Uthes and Matzdorf, 2013).

To sum up, a selectivity effect rules out potential AECM participants and areas. The payments do not include a component beyond the extra-costs of providing positive externalities (ES) that would also remunerate the intrinsic social value of ES. The main reason for that is that AECM were designed as green-box measures with no trade-distorting effects to comply with the World Trade Organisation regulations of the Uruguay round (1994). Therefore, AECM payments, as public policy instruments, can only include profit foregone and additional costs (Uthes and Matzdorf, 2013). As a result, the compensation levels are sub-optimal and make the policy socially inefficient. Espinosa-Goded et al. (2013) remind that taking a supply-side approach to determine the payment without considering social demand for ES can only lead to a sub-optimal allocation. The demand considered to decide of the relevance of implanting a specific measure in a specific area, estimate the budget allocated to the policy instrument and the payment level to farmers is not defined according to a target of socially optimal public good provision (Equation (1.2)). Rather, it is defined according to a target of improving a non-optimal provision, towards a state that likely remains sub-optimal (Duval et al., 2016). Yet, the overall budget allocated to AECM is particularly low in comparison with the CAP income support instruments with no or little environmental conditionality (Dupraz and Guyomard, 2019; European Court of Auditors, 2017; Grethe et al., 2018; Matthews, 2013).

Due to the selectivity effect, the environmental additionality of AECM is also hindered. According to a review by Uthes and Matzdorf (2013), the main ecological effects evaluated were on biodiversity and often case-specific (Uthes and Matzdorf, 2013). Most of the reported benefits were maintenance effects, rather than improvements. Moreover, 24% of the agri-environmental measures evaluated by the European Court of Auditors in 2008 had no positive environmental effect demonstrated (European Court of Auditors, 2011).

Among the set of contracts farmers can uptake, the AECM chosen by the farmers are often the ones with relatively lower transaction costs, which also tends to prescribe ES with low environmental effort (Dupraz and Pech, 2007). In addition, there is a lack of connected network of plots under the same measure: lack of landscape scale results (Uthes and Matzdorf, 2013). The lack of geographical targeting of the policy has been denounced (Cullen et al., 2018). There was an attempt to improve targeting by limiting some measures to specific areas. This change was mostly motivated by public expenditure savings and was accompanied by a decrease in compensation amounts, leading to no improvement (Dupraz et al., 2007). Scholars point out that while it is less costly to reach ecological thresholds in extensive agricultural landscapes, triggering the agroecological transition of intensive agricultural landscapes is more urgent to

avoid more public bads (Uthes and Matzdorf, 2013). Participation is particularly low in intensive production systems due to higher opportunity costs, while it is where ES are the most underprovided (Zimmermann and Britz, 2016).

A final criticism of AECM concerns the set of requirements (the ES farmers must provide) conditioning the delivery of the payment. The policy has been criticized for being too top-down in the design of its requirements (Uthes and Matzdorf, 2013). Today, most AECM are prescriptions of a set of management activities (action-based payment) (Cullen et al., 2018). The contracts do not give incentives for dynamic adaptation of practices, hence there are no incentives for entrepreneurial creativity and the implementation of the most efficient ES for providing the desirable agri-environment-climate public goods (Uthes and Matzdorf, 2013).

The experience of AECM over the last 30 years highlighted key points regarding PES design. Poorly designed instruments lead to low and scattered participation, and insufficient effort to reach environmental thresholds (Dupraz et al., 2009; Zavalloni et al., 2019). Low financing leads to self-selection of farms with low compliance costs and environmental additionality (Cullen et al., 2018; Duval et al., 2016; Uthes and Matzdorf, 2013; Zimmermann and Britz, 2016). Nevertheless, AECM are the CAP instruments the most targeted towards public good provision and with the best potential of providing environmental benefits (Batáry et al., 2015; Dupraz and Guyomard, 2019; European Court of Auditors, 2020; Matthews, 2013).

1.2.2. Diversity of payment for environmental services financing mechanisms

The financing mechanism of PES describes how contributions to finance PES are collected (Pagiola and Platais, 2002).

The AECM from the CAP illustrate the first (and the main) observed type of public PES financing mechanism in the EU. Contributions are collected from EU taxpayers, and an intermediary public authority (EC and Member States) decides how to allocate the budget to policy instruments targeting agri-environment-climate public goods on behalf of the citizens. Beyond AECM, organic farming support (OFS) (maintaining or converting to organic farming) follows the same mechanism (Stolze et al., 2016). In addition, some of the contributions from taxpayers can be indirectly channelled towards PES through other CAP instruments, for instance through the LEADER programme (Duval et al., 2019b). Yet, the money allocated to

finance environmental incentives is too low relative to the total CAP budget and its ambitions (Dupraz and Guyomard, 2019; Matthews, 2013).

Other types of financing mechanisms are developing in parallel to CAP instruments, and capture the willingness to pay of other contributors.

A second type of public financing mechanism involves local authorities and government agencies as intermediaries, collecting fees and taxes from whom Wunder (2015) calls “users” of ES, namely companies charged for polluting activities, and households and companies charged according to their extraction and use of natural resources. Some of this money can be channelled towards co-funding of AECM and OFS, or other PES to farmers. For the latter, one can find examples of successful water quality-related PES financed by municipalities: large ones like Munich in Germany, or smaller ones like Lons-le-Saunier in France (Duval et al., 2019a; Grolleau and McCann, 2012). Other PES involve water and conservation agencies as intermediaries (Agences de l’eau, 2022; Klimek et al., 2008; Molenaar, 2013). Those initiatives are still scarce but developing, when a public financer has a high WTP due to the opportunity of reducing high treatment costs of drinking water production for instance.

Some financing mechanisms have been developed to encourage voluntary initiatives from the private sector. In France, many take the form of voluntary donations to funds financing PES coordinated by intermediaries and targeting climate change mitigation (ex: Eco-Methane for reducing enteric methane emissions, Climat Local and Carbocage for planting and maintaining hedgerows). Those donations can be part of the corporate social responsibility strategy of firms and/or aims at compensating part of their negative environmental externalities (Chambres d’Agriculture des Pays de La Loire et de Bretagne, 2017; Duval et al., 2019b). Through coordinating intermediaries (associations, organisations), some private PES collect public and private donations (Eco-Methane, Carbocage) (Duval et al., 2016). Due to their voluntary nature, the contributions collected through this mechanism are low. The certification of some carbon-related PES and the official recognition of units of compensated GHG emissions (ex: Label Bas Carbone in France) might encourage more contributions in the future.

Private financing initiatives also arise without an intermediary. Some producer cooperatives developed their own PES (ex: Vignerons de Buzet paying voluntary vine growers for reducing insecticides use) (Duval et al., 2019b). Examples also exist from companies for which the

business depends on natural resources and well-functioning ecosystem services (ex: Nestlé Waters having financed the transition of farmers to extensive practices) (Perrot-Maitre, 2006). Finally, a last type of private financing mechanism is purchasing agricultural commodities with the joint provision of ES in the market (Wunder, 2005). The financing mechanism is a price premium charged to end consumers, while the initiator of the payment can be any operator of the value chain (retailer, distributor, brand owner...). In particular, there are now more and more eco-certified food products, although most remain niche markets. Some are official certifications (organic), while others are private brands (BBC, LU Harmony, La Nouvelle Agriculture, Haiecobois) (Bottega and De Freitas, 2009; Duval et al., 2019b).

The main types of financing mechanisms identified from the literature are summarised with an example from France in Table 1.2. Other examples in the EU and beyond are available in (Eichhorn et al., 2022) and on the website of the CONSOLE H2020 project (<https://console-project.eu/>).

Table 1.2. Payments for environmental services mechanisms to allocate the willingness to pay of contributors in France.

Contributor	Financing mechanism	Payment mechanism	Example
EU taxpayers	Budget allocation to common agricultural policy instruments by public authorities	Dedicated payment (profit foregone and extra-costs), no double funding	270 million € per year for Agri-Environment-Climate Measures
Pollution taxpayers (ex: companies selling pesticides) Payers of fees for extracting and using natural resources (ex: water and sanitation)	Project calls and co-funding of common agricultural policy instruments by local public authorities and government agencies	Dedicated payment (profit foregone and extra-costs), “de minimis” cap, no double funding	19.3 million € in 2020 from water agencies for local PES around water catchment areas, Agri-Environment-Climate Measures targeting water quality, and support to organic farming
Private companies	Donation to an intermediary coordinating a PES	Dedicated payment, based on company willingness to pay	7,500 € per year (with a 60% tax deduction) on average by company to the Eco-Methane fund for reducing enteric methane emissions on dairy farms (around 7.5€/tCO ₂ eq)
Private companies	Investment	Dedicated payment, based on (bilateral) negotiation	1.6 million € per year during 7 years from Nestlé Waters for the conversion of 37 farmers to environment-friendly practices
Customers of agricultural commodities	Purchasing budget	Price premium, based on the market price	13 billion € of sales revenue of the organic market in 2021.

Source: own elaboration, using data from (Agence bio, 2022; Agences de l’eau, 2022; Bleu-Blanc-Coeur, 2022a; DDT Ariège, 2020; Déprés et al., 2008; Perrot-Maitre, 2006).

1.2.3. Diversity of payment for environmental services payment mechanisms

The payment mechanism of PES describes how the money collected from contributors is distributed to farmers (Pagiola and Platais, 2002). In addition, some rules may frame how much farmers can receive. Following the identification of the main limits of AECM which are the absence of an incentive component in the payment and the dominance of action-based payments, I focus my review on the definition of the payment amount and the conditionality rules describing the type of ES farmers commit to provide to receive the payment in existing payment mechanisms.

With public PES, the payment is often an annual payment dedicated to ES provision fixed by an assessment of opportunity costs, during the length of a contract between a public authority and a farmer (Espinosa-Goded et al., 2013; European Court of Auditors, 2011; Illes et al., 2017). The payment amount is constrained by public law and cannot go much beyond profit foregone and extra-costs (cost-based approach) nor be differentiated from one farmer to another in the same local context (Duval et al., 2016). When the public budget is low, eligibility criteria to target recipients based on the likelihood of additionality are introduced (European Court of Auditors, 2011). It is the case for AECM participation in France, for which only farms from pre-defined areas are eligible (MAA, 2021a). Auction mechanisms are also implemented to select farmers offering the highest environmental benefits for a low WTA (Klimek et al., 2008; Latacz-Lohmann and Schilizzi, 2005).

Private PES have more flexibility for negotiation between the contributor (or the intermediary) and the farmer. Reaching a mutual agreement favours a payment amount which would go beyond a simple compensation, and include the covering of fixed costs and transaction costs (Duval et al., 2019b). In the case of the PES implemented by Nestlé Waters dedicated to the protection of water quality, the payment mechanism included a negotiation farm per farm (Perrot-Maitre, 2006). The bargaining power of farmers is facilitated by the definition of a collective supply of ES (Duval et al., 2016). Hence, some local initiatives emerge from bottom-up approaches led by farmer groups proposing a collective supply of ES and a payment based on their WTA, to be met by potential financiers (Bailly et al., 2022). When the incentive is joint product market differentiation (value chain included PES), the payment mechanism is a price premium. What the farmer receives depends on the market equilibrium of supply and demand, and the distribution of the premium within the value chain. For instance, the premiums of the French “Bleu-Blanc-Coeur” (BBC) and the Dutch “On the way to planet proof” private labels

distributed to dairy farmers are on average 20€/1000L (6-10% above standard milk price) (Bleu-Blanc-Coeur, 2020; Vermunt et al., 2022). Similarly to dedicated PES, collective initiatives of farmers also increase the bargaining power of ES providers in the negotiation of the price premium with distributors and retailers in the value chain (ex: organic honey from the Stara Planina Mountain in Bulgaria) (Eichhorn et al., 2022).

The conditionality rules of the PES define how ES and their offsite public good provision benefits are assessed (Muradian et al., 2010). In current schemes, one can distinguish PES with obligations of means or action-based (the vast majority), and PES with obligations of results or result-based. In addition, PES can include obligations to individual farmers (individual approaches) or to a group of farmers (collective or landscape approaches).

Most PES contracts dedicated to ES (not included in the value chain), in particular public schemes, are action-based, and paid on a per-hectare basis for the implementation of specific prescribed practices or land use (Duval et al., 2019a; Grolleau and McCann, 2012; Uthes and Matzdorf, 2013). Action-based PES have been criticized for their low environmental effectiveness (lack of a clear link between implemented ES and expected off-farm public good provision) (European Court of Auditors, 2011), low cost-effectiveness (farmers are paid regardless they provide public goods), and low attractiveness (Burton et al., 2008; Quillérou and Fraser, 2010).

Following recommendations from scholars and field-practitioners (Pe'er et al., 2020), result-based payments are developing with promising outcomes (Burton and Schwarz, 2013; Chaplin et al., 2021; Klimek et al., 2008; Matzdorf and Lorenz, 2010). The conditionality rules of result-based PES are such that farmers are paid for offsite environmental outcomes (actual environmental results), or an intermediary indicator of that outcome, and are left free to decide their farming practices (Russi et al., 2016). They present several advantages compared with action-based, reviewed by Herzon et al. (2018). Result-based PES are particularly relevant when too little is known about the relationship between management practices and public good provision and/or when this information is expensive to get (Duval et al., 2016). Yet, a result-based PES value farmers' ES on the condition that it is possible to attribute a change in the measured result to farmers' action (Uthes and Matzdorf, 2013). The main obstacles to the implementation of result-based PES are increased risks for farmers and the difficulty to find a good environmental result indicator (Massfeller et al., 2022; Zabel and Roe, 2009a). Public result-based PES were mostly developed for grassland biodiversity, with a payment per hectare

meeting an environmental objective (Andreoli et al., 2022; Bartkowski et al., 2021; Eichhorn et al., 2022; Herzon et al., 2018; Klimek et al., 2008). In the private sector, some PES targeting climate mitigation propose a payment proportional to reduced or stored tCO₂eq, which is an internationally-recognised convention unit (Duval et al., 2019b; Eichhorn et al., 2022). Indicators for result-based PES for general biodiversity are more difficult to generalise and must be adapted to the local context (Alston et al., 2013; Landell-mills and Porrás, 2002). Existing schemes use intermediate measures on umbrella species indicating a good state of conservation of the ecosystem or habitat (Andreoli et al., 2022; Bartkowski et al., 2021; Klimek et al., 2008).

As for the organic label, value-chain included PES typically rely on obligations of complying with strict requirements on input-use and management practices (standards) which can be controlled and eventually certified by a third party (Bruce and Laroiya, 2007; Duval et al., 2019b; Erickson and Kramer-Leblanc, 1997; van Amstel et al., 2008). While they are dominantly action-based, some operators of the supply chain include result-based top-ups to the farmer price premium if environmental indicators are improved (Eichhorn et al., 2022).

Similarly to result-based approaches, collective approaches have been tentatively emerging as a way to improve the environmental-effectiveness of PES. Currently, most PES are defined at the individual plot or farm scale. For public goods for which the provision is site-specific (biodiversity, water quality), landscape approaches favour reaching ecological thresholds. In the 2014-2020 CAP programming period, several collective AECM have emerged, mostly in the Netherlands (Franks, 2011; Verhulst et al., 2007), but also, more scarcely, in other Member States such as in France, Germany, England or Wales (Eichhorn et al., 2022; Franks, 2019; Prager, 2015). The conditionality rules are such that the payment is delivered if a group of farmers from the same area (cooperative or association) meets the contract requirements rather than individual farmers. Beyond collective contracting, collective approaches can take various forms from coordination to collaboration in the implementation of ES (see review by Prager, 2015). In particular, those initiatives aim at ensuring spatial coordination of ES, such as continuity over adjacent plots to form ecological corridors, or over all the upstream lands of a watershed (Alston et al., 2013; Prager et al., 2012; Villamayor-Tomas et al., 2021; Westerink et al., 2017). Apart from pilot projects (Bailly et al., 2022), examples from the private sector are difficult to find. In the case of the PES by Nestlé Waters for its mineral water brand Vittel, the farm by farm negotiation process aimed at ensuring spatial agglomeration of environmental commitments, even though there was no collective incentive per se (Perrot-Maitre, 2006). The

main obstacles to collective PES are increased risks for farmers whose payment depends on others' compliance, and the difficulties to create and maintain a group dynamic (Prager, 2015).

The review of the literature on PES mechanisms shows the diversity of financing mechanisms and payment mechanisms. Three main issues of mismatch between farmers' supply and social demand were identified with the current dominant PES (dedicated public schemes). First, the financing mechanisms do not capture enough WTP to meet farmers' WTA and favour a large-scale adoption by farmers (low demand from contributors). Second, the payment mechanisms tend to focus on paying for individual on-farm practices, and do not favour environmental effectiveness and result in a low supply of public goods. Third, current public payment rules constrain the payment to be a compensation rather than an incentive, which makes the adoption of PES unprofitable to many farmers (low supply of ES). Some new types of PES let us foresee potential levers for improvements. Higher demand from contributors can be expressed by dedicating more public money to environmental instruments (upscaling dedicated public schemes), and/or developing financing mechanisms capturing private WTP (dedicated private PES or integrated into the food value chain). Moreover, the supply of public goods by farmers can be enhanced by integrating more result-based and collective approaches, to improve the environmental effectiveness of PES by conditioning the delivery of the payment to an off-farm environmental benefit (the public good provision for result-based, or a landscape achievement facilitating public good provision for collective).

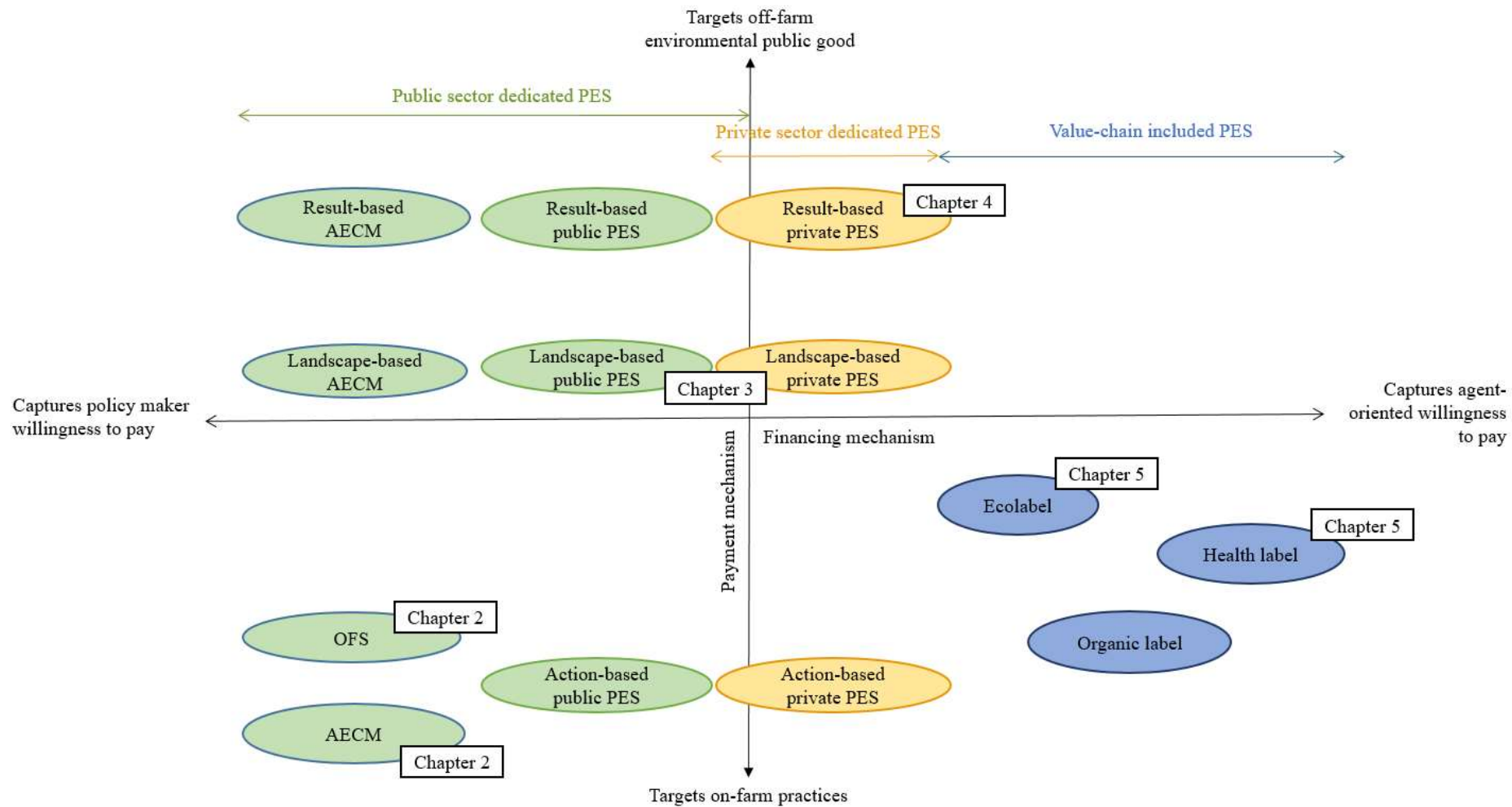
1.3. Problem statement, objective and research questions

The general objective of my thesis is to analyse with theoretical and empirical approaches, the efficiency of two polar cases of PES: (i) the remuneration by public authorities of voluntary ES by farmers (dedicated public schemes), (ii) the creation of a label on an agricultural commodity aiming at remunerating an ES by consumers (schemes integrated in the value chain).

In my thesis, I decided to define an analysis grid according to two dimensions: (i) the targeting of the payment mechanism, and (ii) the financing mechanism mobilising the WTP of contributors. As seen previously from the literature review, more result-based approaches are encouraged to increase the environmental effectiveness of PES. The first axis allows us to situate a PES according to whether the payment is conditional on the means implemented by individual farms (targeting on farm practices) or on off-farm environmental benefit (targeting

off-farm environmental public good) (Figure 1.3). For instance, it differentiates action-based AECM (ex: payment per hectare for not ploughing a grassland) from result-based PES (ex: Eco-Methane with a payment proportional to reduced enteric methane emissions per litre of milk). I situate landscape approaches in the middle of this axis, as they are targeted towards off-farm achievements to favour reaching ecological thresholds for public good provision, but can include requirements of practices or environmental results depending on the scheme design. The second axis classifies a PES according to whether it is financed by the taxpayer (mobilisation of an aggregated WTP on behalf of public good beneficiaries) or by voluntary contributors following their individual WTP (mobilisation of agent-oriented WTP directly by the agent itself) (Figure 1.3). In theory, for the former, public authorities intervene to aggregate individual WTP for the public good and define the payment to ES providers to reach optimal provision according to the BLS condition. In practice, the WTP and the payment set by the public authority may strongly differ from the optimum, because of budget constraints, other competing priorities, and the lack of information on environmental processes, consumers' WTP for public goods and farmers' WTA to provide ES. For the latter, the WTP of an individual agent (consumer) is financing the PES, suboptimally because of non-rivalry and the possibility of free riding. For public goods set aside by public policy, capturing the WTP of consumers might be better than nothing. For public goods insufficiently supported by public policies, it might complement poor funding. This second axis differentiates between the two polar cases of PES, which are the AECM financed via the CAP and the premium paid by consumers of a labelled product for the joint provision of ES. I summarise public dedicated PES that are not CAP instruments under "public PES", and private dedicated PES under "private PES". Based on this reading grid, I formulate four research questions I tackle in my PhD thesis.

In the next three chapters of the thesis, I evaluate different levers to upscale PES adoption by farmers, specifically addressing the limits and inefficiencies of current mechanisms identified in the previous sections: (i) increase the budget allocated to current public dedicated PES instruments in the CAP (chapter 2), (ii) introduce incentives for collective dynamics in the payment mechanisms when targeting public good provision with ecological thresholds effects (chapter 3), (iii) design result-based payment mechanisms (chapter 4). To complement limited public funding and insufficient voluntary contributions from private actors, I propose to capture more contributions from consumers by developing official labels with information on the private benefits (ex: health) from consuming agricultural commodities produced jointly with ES (chapter 5).



PES: payments for environmental services. AECM: agri-environment-climate measures. OFS: organic farming support
 Source: own elaboration

Figure 1.3. Payments for environmental services mechanisms to tackle the underprovision of public goods by agriculture.

Research Question 1: Can AECM be upscaled by targeting more public money towards the provision of public goods?

Chapter 2 focuses on a scenario of changing the allocation of the CAP budget to target more taxpayers' money towards the provision of public goods. Today, environmental incentives are severely underfunded relative to income support payments (direct payments in the CAP), which limits their attractiveness to farmers. The hypothesis is that a shift in budget from direct payments to environmental payments would increase the voluntary adoption of ES without requiring additional funding from the taxpayer. Two effects are envisaged: (i) a direct effect of the increase in the budget allocated to environmental instruments, (ii) an indirect effect of the decrease in direct payments. Using French data from the Farm Accountancy Data Network (FADN), we simulate the effect of a transfer of 7.5% of direct payments to OFS and AECM. The type of PES studied is located at the bottom left of the analysis grid, as the vast majority of PES financed by the CAP in France are action-based. Results suggest this mechanism increases participation in environmental schemes with decreasing returns relative to the budget increase. The methodological approach can be adapted to evaluate different budget allocation scenarios and provides ex-ante elements on farmers' response to more targeted public support towards the provision of ES.

Another lever for better allocating contributions is the payment mechanism. One source of inefficiency in individual PES with action-based is that they pay for practices with no environmental additionality if the ES requested are not ambitious enough and/or not adapted to the public good targeted. Making all or part of the payment conditional on a relevant landscape approach including several farms when the targeted public good has threshold effects, or directly on an obligation of result, would allow greater environmental effectiveness.

I first focus on PES with a collective or landscape approach, which may be publicly and/or privately financed. Their performance in securing more public good provisions depends in particular on their acceptability by farmers. Introducing landscape-approach conditionality in the form of a bonus payment to trigger higher agglomeration and an off-site environmental result has the advantage of limiting the risks for farmers.

Research Question 2: Could a conditional bonus increase farmers' commitment and encourage them to exceed ecological thresholds?

Elaborating on Kuhfuss et al. (2016), chapter 3 applies a choice experiment approach and aims at measuring farmers' preferences for a PES contract with a payment for which part of it is conditional on the sponsorship of other farmers on the territory (sponsorship bonus) and/or a collective environmental result (water quality improvement). Two hypotheses are underlying: (i) the sponsorship bonus allows to recruit more farmers on the same territory and to increase ES commitments at the landscape scale, and therefore favours the provision of threshold public goods, (ii) the collaborative effect of the sponsorship bonus can be reinforced by a collective reward for the achievement of an environmental result on the territory. We propose higher levels of payment than what is currently proposed in AECM, considering that the involvement of other contributors (water bodies, municipalities, companies...) would allow financing beyond opportunity costs and get closer to farmers' WTA. Results show respondents prefer contracts with a sponsorship bonus to no bonus, but lower and heterogeneous preferences for the combined sponsorship/collective bonus for environmental achievement. We identify three behavioural patterns regarding the bonus option: indifference, acceptance and non acceptance. We find the sponsorship bonus option can improve PES cost-effectiveness, and suggest the combined bonuses can be cost-effective insofar as the individual per-hectare payment remains high enough to secure an environmentally effective participation level.

I then explore the design of result-based dedicated PES. In theory, paying for results is the most targeted payment mechanism towards public good provisioning. Nevertheless, the environmental effectiveness of the payment is only assured if the result is precisely measured and properly remunerated.

Research Question 3: What are the technical elements to consider when defining a payment proportional to the environmental outcome?

Based on an existing PES with a result obligation, the Eco-Methane PES (Le Gloux et al., 2021), Chapter 4 explores the adoption of practices that reduce enteric methane emissions from dairy cows through the implementation of a payment conditional on the units of CO₂ equivalents

reduced per litre of milk. We show the importance of taking into account the herd's grass feed intake (i) in the choice of the emissions indicator defining the unit of payment to accurately measure the ES, (ii) in the definition of the level of payment to take into account the difference in the additional cost of a change in dairy cow diet. Our results show the relevance of using an emission indicator sensitive to diet effects, and that French dairy systems in mountains and plain areas with already a large share of grasslands would face high and significant extra-costs for adding more grass to the feed ration. We stress the importance of developing PES with well-defined environmental indicators and funding requirements accounting for the technical problem addressed.

Finally, I turn towards PES integrated into the value chain to capture consumers' WTP. Since consumer contributions are voluntary, economic theory shows that eco-labels (and other private schemes) are inefficient instruments because individuals finance up to their own individual marginal utility without considering the utility of other non-rival consumers. However, the opportunity offered by labels is that consumers can express their WTP for all product characteristics. Some practices providing ES also improve the quality of the joint agricultural product (ex: enriching dairy cow rations with grass fodder both reduces enteric methane emissions and enriches milk in omega-3 fatty acids), for which consumers also have a WTP.

Research Question 4: Does labelling on the complementary provision of private benefits increase the effectiveness of ecolabels?

In the fifth chapter of the thesis, we focus on the case where the provision of ES is complementary to the production of an agricultural product providing health benefits. We develop a theoretical model of impure public goods adapted from Kötchen (2005) to study the provision of a global public good through three labels (environmental label, health label, health and environment label), and derive the optimality conditions according to the objectives of a social planner, an environmental agency or a health agency. We show that higher public good provisioning occurs through a health label than an environmental label in most situations. The extent of this result depends on the consumers' preferences and the market size. The public good remains underprovided in all market settings from the perspective of a social planner.

However, under certain conditions, a health label and a health and environment label will lead to the optimal provisioning of the public good from the perspective of an environmental agency.

1.4. Outline of the PhD thesis

My PhD thesis is organised into six chapters. Chapter 1 is this general introduction. Chapter 2 to 5 are research articles aiming at answering the research questions presented in the previous paragraph. Chapter 2 (Le Gloux and Dupraz) develops an empirical ex-ante evaluation method of a transfer of budget from direct payments to AECM and organic farming support within the framework of the CAP. Chapter 3 (Le Gloux, Dupraz, Issanchou, and Ropars-Collet) presents a choice experiment to empirically measure farmers' preferences for a PES contract with a bonus payment conditional on the sponsorship of other farmers on the territory and/or a collective environmental result. Chapter 4 explores empirically the design of a result-based PES for reducing enteric methane emissions from dairy cows. Chapter 5 develops a theoretical model of impure public goods and compares the provision of a global public good through three labels (environment label, health label and health and environment label) in the case where the provision of public good is complementary to the production of a healthy agricultural product. Chapter 6 is a general discussion of the main scientific and methodological contributions of the PhD, and the limits and perspectives of the work done.

Chapter 2. Upscaling environmental incentives in the Common Agricultural Policy: an ex-ante evaluation method applied with the Farm Accountancy Data Network

In this chapter, I assess the adoption of environmental incentives in the framework of the Common Agricultural Policy (CAP). Agri-environment-climate measures (AECM) and support to organic farming (OFS) are the two main instruments supporting environmental services in the European Union (EU) since the early 1990s. They have been insufficient in reaching significant environmental improvements, in particular, because they are under-funded in comparison with income support instruments with no or little environmental conditionality (direct payments).

In this study, I aim at evaluating the lever of better targeting the CAP public budget towards instruments for public good provision. Using France's panel data of the farm accountancy data network (FADN), I develop an ex-ante evaluation method at the national scale describing farms' AECM and OFS adoption and simulate a change of budget allocation between direct payments and environmental incentives. First, I apply a generalised Tobit model estimating the probability of environmental contract adoption and the minimum farm level payment triggering adoption (acceptable payment) using 2015-2019 panel data. Second, I simulate a 7.5% shift in budget from direct payments to OFS and AECM in 2019.

This chapter was co-authored with Pierre Dupraz (INRAE, SMART), and involved the following individual contributions: Fanny Le Gloux: conceptualisation, formal analysis, investigation, methodology, validation, original draft; Pierre Dupraz: conceptualisation, methodology, supervision, validation. A preliminary version of the model was used to simulate a scenario for the new CAP 2023-2027 for which the results were published in (Chatellier et al., 2021). Preliminary results were also presented at the 9th Annual Conference of the French Association of Environmental and Resource Economists (8th-9th September 2022 in Rouen, France). The analyses contributed to the deliverables D3.1 (Dupraz et al., 2022) of the CONSOLE H2020 project (<https://console-project.eu/>).

2.1. Introduction

The European Union (EU) adopted ambitious environmental targets by 2030 and 2050, in particular on the development of organic farming to reach 25% of organic agricultural land by 2030. Following the definition of the Biodiversity Strategy for 2030 and the Farm to Fork Strategy for the agricultural and food sectors, rethinking the design of the Common Agricultural Policy (CAP) and its instruments is central to trigger the large-scale agro-ecological transition of farming systems (EC, 2020a, 2020b).

The agricultural sector accounted for 10% of the EU's greenhouse gas (GHG) emissions for the period 1990 to 2018 and is the second largest contributor after the energy sector (EEA, 2020b). The continuous intensification of agricultural activities also contributed to natural habitat degradation and dramatic biodiversity decline (Dasgupta, 2021). Behind the concept of agro-ecological transition lies the idea of moving away from agricultural practices harming ecosystem services, in particular the systematic use of chemical inputs, towards farming systems maintaining or supporting them (Millennium Ecosystem Assessment, 2005). Many levers at various scales can foster this transition. An important one is a better targeting of agricultural support to make agro-ecological farming more profitable than conventional farming (FAO et al., 2021).

The CAP represented 36% of the 2019 EU's budget (58.4 billion euros) (EC, 2019) and is the main EU policy supporting environment-friendly farming practices. Environmental incentives are offered in two voluntary 5-year contractual schemes of the rural development pillar of the CAP: (i) support to organic farming (OFS), and (ii) agri-environment-climate measures (AECM). OFS are area-based payments to eligible farms undertaking a conversion towards OF, or to eligible certified organic farms for maintaining their organic practices. This instrument has proven to be effective in maintaining the relative competitiveness of organic farming and is a major driver of the sector development (Casolani et al., 2021; Sanders et al., 2011). AECM are area-based payments to eligible farms complying with a set of management requirements targeting an environmental objective such as the maintenance of biodiversity or the improvement of water quality. They are the CAP instrument the most targeted towards public good provision (Batáry et al., 2015; Dupraz and Guyomard, 2019; European Court of Auditors, 2020; Matthews, 2013). The literature shows that after 30 years of existence, the voluntary environmental schemes of the CAP are unsatisfactory to improve the state of the environment. The lack and unbalanced funding, as well as poorly designed instruments, led to insufficient

participation and effort to reach environmental thresholds (Dupraz et al., 2009; Dupraz and Pech, 2007; Espinosa-Goded et al., 2013; Zavalloni et al., 2019). In 2020, only 13% of the EU's UAA was under an AECM contract, and 6% under an OFS contract (EC, 2020c, 2020d).

The budget allocated to environmental contracts is low in comparison to income support payments (direct payments), the latter including little restrictions on agricultural practices (Dupraz and Guyomard, 2019; European Court of Auditors, 2017; Grethe et al., 2018; Matthews, 2013). In 2019, direct payments accounted for 69% of the CAP budget (40.5 billion euros), while 8.6% (3.5 billion euros) was allocated to OFS, AECM and Natura 2000 sites altogether (EC, 2019).

Environmental benefits imply high uptake of environment-friendly practices. This can be done by more targeted support and less “untargeted” support. Rather than increasing the CAP budget to raise environmental incentives, many argue in favour of rebalancing the budget allocation (Dupraz and Guyomard, 2019; Matthews, 2013). Since the 2014-2020 CAP programming period, Member States have the flexibility to transfer up to 15% of their direct payments budget to increase support to rural development measures, including OFS and AECM (EU, 2013a). In France, 7.5% of direct payments have been redirected since 2017 (MAA, 2021b). In this study, we aim at simulating further reorientation specifically towards the environmental contracts of the rural development pillar in France. It has been one of the scenarios for the CAP 2023-2027, preliminarily evaluated by (Chatellier et al., 2021). Although the negotiations ruled out this option for the CAP 2023-2027, a similar mechanism will dedicate 25% of direct payments to finance a new instrument (eco schemes) open to all farmers and supporting the voluntary implementation of environment-friendly measures (generally less ambitious than OFS or AECM contract requirements) (EC, 2021b; Runge et al., 2022).

Our first contribution is an ex-ante evaluation method of the transfer mechanism from direct payments to environmental contracts. In particular, we model the impact on adoption. To our knowledge, the effect of such a budget transfer has not yet been assessed at the farm level and for an allocation targeting environmental contracts specifically. Previous ex-ante evaluations of the reorientation of direct payments used the CAPRI (Common Agricultural Policy Regionalised Impact) partial equilibrium model (Himics et al., 2020; Schroeder, 2021; Schroeder et al., 2015), or linear programming (Giannakis et al., 2014), to study the impact on environmental indicators aggregated for farm types and EU regions. Hence, it remains unsure how effective it can be to significantly increase the voluntary adoption of environment-friendly

practices at the farm level, and what are the underlying microeconomic mechanisms. We develop our model with observed data, and assume a transfer towards existing contracts during the 2014-2020 CAP programming period: OFS and AECM. Using panel data from the farm accountancy data network (FADN), we propose a generalised Tobit model estimating the adoption decision and the farm-level payment (acceptable payment) triggering adoption. Adoption results from the confrontation of the supply of environmental commitments by farmers (farm and farmer characteristics, opportunity costs), and demand from public authorities (budget, eligibility criteria, contract requirements, payment). Our model partly overcomes the absence of information on specific contract characteristics and eligibility criteria by controlling for many factors of farm heterogeneity. The estimations are used to simulate contract uptake in 2019 under a new budget allocation.

Beyond a direct positive effect on the participation of an increased budget available to finance environmental contracts, one can expect an indirect effect of lower income support on farmers' response to environmental incentives. Monetary aspects from different sources, including direct payments, are important drivers of the decision to adopt AECM and organic farming (Darnhofer et al., 2019; Jaime et al., 2016; Sanders et al., 2011; Van Herzele et al., 2013). Allaire et al. (2011) and Pufahl and Weiss (2009) found different effects of direct payments coupled to production on participation in AECM, with an overall positive effect in Germany, and a marginal or negative effect in France for extensive grassland measures. Moreover, a positive effect of the decoupling of direct payments on the adoption of organic farming was found in Sweden (Jaime et al., 2016). Our second contribution is to capture the effect of direct payments on the contract adoption decision and acceptable payment in France under the 2014-2020 CAP framework.

The remaining of the paper is organised as follows. Section 2.2 presents the theoretical framework and econometric model of environmental contract adoption, the data and the procedure to simulate a reorientation of CAP budget. Section 2.3 describes the estimated econometric models. Section 2.4 presents the simulation results. Finally, section 2.5 discusses the findings and draws some conclusions.

2.2. Materials and methods

Our methodological approach to simulate a change in CAP budget allocation comprises three steps:

1. Estimation of the model of voluntary contract adoption under the current budget allocation.
2. Prediction of new probabilities and acceptable payments with a reduction of direct payments.
3. Starting from the farm with the highest probability to participate, allocation of the initial instrument budget plus an additional amount from the direct payments budget to participants, up to their estimated acceptable payment, until the budget is exhausted.

2.2.1. Theoretical model of voluntary adoption of an environmental contract

We represent the demand for environmental commitments from authorities during a CAP programming period by a function $\theta(M, B, \Gamma)$ describing a set of contracts M , a total budget B , and policy parameters Γ defining environmental contracts exclusion rules. The confrontation of demand and supply of environmental commitments results in an uptake equilibrium such that $B = \sum_i P_i(M, \Gamma_i, \gamma_i, k_i, e_i)$. With P_i the farm-level payment allocated to farms, Γ_i the farm characteristics affecting exclusion to environmental contracts (location in eligible area), γ_i the farm characteristics affecting eligibility to a subset of environmental measures of M (location, land use, organic certification status), k_i other farm and farmer characteristics (economic size, surface, age, education, technical orientation...), and e_i the farm economic context (market prices, CAP support...).

We assume the supply of environmental commitments by farmers is driven by the profitability of adoption and eligibility. The decision D_i^* of farmer i to participate and the binary participation D_i are defined as follow:

$$D_i = \begin{cases} 1 & \text{if } D_i^* \geq 0 \\ 0 & \text{otherwise} \end{cases} ; D_i^*(M, \Gamma_i, \gamma_i, k_i, e_i) = \Phi_i(m_i^*, \Gamma_i, \gamma_i, k_i, e_i) - P_i^*(m_i^*, \gamma_i, k_i, e_i) \quad (2.1)$$

With $m_i^* \in M$ the characteristics of the contract(s) adopted by the farm (technical requirements, payment per hectare), $\Phi_i \geq 0$ the maximum payment the farm is eligible to for adopting m_i^* , and $P_i^* > 0$ the farm-level payment triggering the adoption of m_i^* (acceptable payment). $m_i^* = m_i^*(M, \Gamma_i, \gamma_i, k_i, e_i)$ is the optimal contract uptake and the solution to the profit maximisation programme of farm i . $\Phi_i(m_i^*, \Gamma_i, \gamma_i, k_i, e_i)$ is the total payment the farm can

receive for enrolling all eligible surfaces under m_i^* . $P_i^*(m_i^*, \gamma_i, k_i, e_i)$ is the minimum payment farm i should receive for accepting to enrol the profit maximising share of eligible surfaces under m_i^* . If $\forall m_i \in M, \Phi_i(m_i, \Gamma_i, \gamma_i, k_i, e_i) = 0$ or $0 < \Phi_i(m_i, \Gamma_i, \gamma_i, k_i, e_i) < P_i^*(m_i, \gamma_i, k_i, e_i)$ (the farmer is not eligible or participation is not profitable), then $D_i^* < 0$ and the farm is not participating. If $\exists m_i \in M, \Phi_i(m_i, \Gamma_i, \gamma_i, k_i, e_i) \geq P_i(m_i, \gamma_i, k_i, e_i)$, the farmer is eligible to at least one contract profitable for him or her, and the farm decides to participate with the optimal contract uptake m_i^* such that $D_i^* \geq 0$. In this setting, the farm-level payment allocated to farms P_i is:

$$P_i(M, \Gamma_i, \gamma_i, k_i, e_i) = \begin{cases} P_i^*(m_i^*(M, \Gamma_i, \gamma_i, k_i, e_i), k_i, e_i) & \text{if } D_i^*(M, \Gamma_i, \gamma_i, k_i, e_i) \geq 0 \\ 0 & \text{otherwise} \end{cases} \quad (2.2)$$

2.2.2. Econometric model of voluntary adoption of an environmental contract

Following the theoretical framework, we aim at estimating a model of adoption of AECM and OFS during a CAP programming period proposing the menu of contracts M . Due to the censored nature of the farm-level payment, an estimation of the acceptable payment with least squares methods is not applicable. We apply a generalised Tobit model (Amemiya, 1984; Wooldridge, 2010) to simultaneously estimate two dependent variables: the decision to participate (selection equation) and the acceptable payment (outcome equation), as functions of observed determinants from a sample of participants and non-participants. Because the adoption behaviour of farmers, in particular the acceptable payment, likely differs between OFS and AECM, we estimate one model for each type of contract.

With panel data, the decision to participate of farmer i in year t , is represented by the latent variable D_{it}^* explained by observed covariates $Z_{it} = (\gamma_i, k_{it}, e_{it})$, environmental contract exclusion criteria Γ_{it} and an error term ε_{it} . The observed farm level participation can be described by a binary random variable $D_{it} = \{0,1\}$ (Equation (2.3)).

$$D_{it}^* = \alpha Z_{it} + \gamma \Gamma_{it} + \varepsilon_{it}, \quad \varepsilon_{it} \sim N(0,1), \quad D_{it} = \begin{cases} 1 & \text{if } D_{it}^* \geq 0 \\ 0 & \text{otherwise} \end{cases} \quad (2.3)$$

Our outcome of interest is the acceptable payment P_{it}^* triggering participation, which is explained by observed covariates $Z_{it} = (\gamma_i, k_{it}, e_{it})$, environmental contract exclusion criteria Γ_{it} and an error term u_{it} . For identification, the outcome equation must include one less

explanatory variable than the selection equation. The payment P_{it} received by participant i at year t is observed (censored variable at zero) (Equation (2.4)).

$$P_{it}^* = \beta Z_{it} + \delta \Gamma_{it} + u_{it}, \quad u_{it} \sim N(0, \sigma^2), \quad P_{it} = \begin{cases} P_{it}^* & \text{if } D_{it}^* \geq 0 \\ 0 & \text{otherwise} \end{cases} \quad (2.4)$$

Without information to characterise the exclusion criteria Γ_{it} , the actual models estimated are the following ones:

$$D_{it}^* = \alpha Z_{it} + e_{it}, \quad e_{it} \sim N(0, 1), \quad D_{it} = \begin{cases} 1 & \text{if } D_{it}^* \geq 0 \\ 0 & \text{otherwise} \end{cases} \quad (2.5)$$

$$P_{it}^* = \beta Z_{it} + v_{it}, \quad v_{it} \sim N(0, \sigma^2), \quad P_{it} = \begin{cases} P_{it}^* & \text{if } D_{it}^* \geq 0 \\ 0 & \text{otherwise} \end{cases} \quad (2.6)$$

And we have an omitted-variable bias on α equals to $\gamma \frac{\text{Cov}(Z_{it}, \Gamma_{it})}{\text{Var}(Z_{it})}$ in Equation (2.5) and on β equals to $\delta \frac{\text{Cov}(Z_{it}, \Gamma_{it})}{\text{Var}(Z_{it})}$ in Equation (2.6).

The latent continuous variable D_{it}^* is estimated with a Probit regression model with the binary variable D_{it} as dependent variable over the sample of participants and non-participants. The acceptable payment is estimated for each farm of the sample based on the estimation of the censored equation (2.4) using the participating farms. We do not impose an upper limit to the estimated acceptable payments to capture the behaviour of farmers requiring a strong financial incentive to participate. We impose that acceptable payments cannot be lower than 300€, which is the minimum required by French public authorities to start a contract (MAA, 2020).

The Tobit regression model provides estimated coefficients of the effect of the explanatory variables on both the decision to participate in an environmental scheme and the farm-level acceptable payment triggering participation. The marginal effects of each variable are evaluated at sample means so that coefficients can be more easily interpreted.

2.2.3. Data

The French Metropole FADN data for the years 2015 to 2019 were used for the analysis. The data were accessed within a secured environment offered by the CASD (centre d'accès sécurisé aux données', Ref. 10.34724/CASD), and represent an unbalanced panel of 36,251 farm

observations, including information on the payment received from AECM and OFS. The dataset does not include information on the surfaces enrolled in each contract, nor on the specific measures adopted. The national FADN is designed to be representative of medium and large farms contributing to more than 90% of the gross production and utilised agricultural area (UAA), and covers the scope of 65% of all farms (Agreste, 2022). This data source is therefore particularly relevant for ex-ante CAP evaluations.

From 2015 to 2019, a total of around 1.6 billion was allocated to the farms of our sample for engaging in AECM and OFS (Table 2.1). The highest budget was for 2019, with 228 million € to 11% of sample farms for AECM and 203 million € to 7% of sample farms for OFS. Information on farms' organic certification allows us to deduct that 66 million € are distributed to 1.5% of sample farms for conversion OFS and 138 million € to 5% of sample farms for maintenance OFS. For that same year (2019), the French Government reported allocating a total of 244 million € for AECM and 249 million € for OFS, including 191 million € for conversion OFS and 58 million € for maintenance OFS (DDT Ariège, 2020). Assuming the total number of farms in France Métropole was the same in 2019 as in 2020 (389,800), we deduct that 11% of French farms contracted an AECM, 5% conversion OFS and 3% maintenance OFS (INSEE, 2022). Hence, our FADN sample describes the allocation of 93% of the AECM budget and 82% of the OFS budget to a representative ratio of participants/non-participants in 2019. However, it does not represent well the repartition between conversion OFS and maintenance OFS, and overestimates the allocation of OFS to certified farms relative to farms in conversion. Yet, we observed the ratio within the OFS-eligible population (i.e. farms converting to organic farming or already certified in 2019) is well represented in the FADN, at least when it comes to the utilised agricultural area (UAA) (see Appendix A1) (Agence bio, 2020).

Based on the literature on the factors affecting AECM and organic farming adoption and our theoretical approach (Allaire et al., 2011; Defrancesco et al., 2008; Elliott and Image, 2018; Espinosa-Goded et al., 2013; Pavlis et al., 2016), we selected a set of variables to model contract uptake.

Table 2.1. Common Agricultural Policy budget and beneficiaries in 2015-2019.

Year	Direct payments	Decoupled direct payments	Coupled direct payments for suckler cows	AECM	OFS	Conversion OFS	Maintenance OFS
Budget (million €) ^{1,2}							
2015	7 288.4	6 095.6	667.5	165.3	122.5	23.6	99.0
2016	6 955.9	5 781.6	631.5	136.5	123.5	18.7	104.8
2017	7 124.9	5 880.6	651.6	159.4	140.0	19.4	120.6
2018	6 727.5	5 576.2	623.7	189.7	147.2	30.6	116.6
2019	6 676.0	5 561.1	655.0	227.9	203.3	65.7	137.6
Beneficiary farms (%)							
2015	85.7	84.1	24.9	6.2	5.6	0.9	4.7
2016	85.5	84.2	25.2	6.6	5.8	0.7	5.1
2017	85.1	83.6	25.9	7.8	5.6	0.6	5.0
2018	85.6	84.4	25.8	8.9	5.3	0.8	4.5
2019	85.3	84.1	26.5	10.8	6.9	1.5	5.4
Beneficiaries' UAA (%)							
2015	97.9	97.3	34.0	8.8	4.2	0.8	3.5
2016	98.4	98.1	34.1	9.1	4.4	0.7	3.8
2017	98.4	98.0	35.3	10.3	4.9	0.5	4.3
2018	98.4	98.1	35.0	11.9	4.9	0.9	4.0
2019	98.6	98.1	35.8	14.5	6.3	1.6	4.7

AECM: agri-environment-climate measures. OFS: organic farming support. UAA: utilised agricultural area.

¹ Cumulated payments are weighted by the extrapolation coefficient of each observation.

² To compute the real instrument budget for year t, we added the delayed payments distributed in year t+1 or t+2. Some of the direct payments for year t (maximum 0.2%) were distributed in t+1 for 2015, 2016, 2017, 2018 and 2018, and in t+2 for 2015 and 2017. Some AECM and OFS payments were distributed in t+1 for 2018 and 2019 (maximum 8.0%). We could not correct for 2019 instrument budgets distributed in 2021 (data not available).

Source: 2015-2020 French FADN data.

Regarding the farm economic context (e_{it}), we control for the effect of CAP direct payments by including the amount of decoupled direct payments received per hectare (*decoupled payment*). We control for the amount of direct payments for suckler cows at the farm level (*coupled payment for suckler cows*) as it is the production receiving the highest coupled support in France. We further control for the cost of land lease per hectare of UAA (*land lease*), and the observed fuel and lubricant price of the farm (*fuel price*), the only variable input price that can be computed with FADN data. Fuel price is likely correlated to other farm input prices on the market (mineral fertilisers), and is an indicator of opportunity costs from adopting less input-intensive agricultural practices. When fuel price is not observed for a given observation (8.4% of the sample), we replace it with the mean of the observed fuel prices from the other years for the same farm (3.3% of the sample), or the annual mean of the sample (5.1% of the sample).

Accounting for farm and farmer characteristics (k_{it}) captures heterogeneous difficulties to meet contract requirements and preferences. We control for economic size (*standard gross production*), UAA (*utilised agricultural area*), total labour per hectare of UAA (*labour*), the share of rented land (*rented UAA*), assets depreciation per hectare of UAA (*depreciation*) and for the reception of LFA payment (*LFA*). We account for farm specialisation (1 dummy per technical orientation or group of technical orientations). Farmers' characteristics are age (*age*) and education (*general education* and *agricultural education*).

Additional explanatory variables were included to control for eligibility to specific environmental measures (γ_{it}) and exclusion (Γ_{it}) of the set M defined by public authorities in the CAP 2014-2020 programming period. Most AECM are implemented at the local level and designed specifically for some land use or areas with high natural value. We control for the share of permanent grasslands in the UAA (*permanent grasslands*), and the load of grazing livestock per hectare (*grazing livestock density*). OFS eligibility depends on the region, with some not proposing maintenance OFS in all or part of their territory. We therefore account for farm location (1 dummy variable per region). Moreover, we add a dummy equals to 1 if half of the farm's UAA is located in a Natura2000 area (*Natura2000*), and one dummy variable equals to 1 if the farm is certified organic (*organic certification*). Controlling for organic certification captures the effect of eligibility to maintenance or conversion OFS, as only certified organic farms can apply to the former. To control for past participation, we estimate the model with 2016-2019 observations, and use 2015 data to construct a variable equals to 1 if the farm

participated in AECM in 2015, 0 otherwise (*observed participation in AECM in 2015*), and a variable equals to 1 if the farm participated in OFS in 2015, 0 otherwise (*observed participation in OFS in 2015*). In addition, we capture part of the interaction between OFS and AECM uptake by controlling for observed participation in AECM (OFS respectively) at time $t - 1$ when estimating the decision to participate in OFS at time t (AECM respectively) (*observed participation in AECM at $t-1$* and *observed participation in OFS at $t-1$*). For model identification, we exclude this latter variable from the simultaneous outcome equation. We have unbalanced panel data and information on past participation is missing for observations which were not sampled the year before.

Finally, we control for year fixed effects.

Descriptive statistics of the covariates are presented in Table 2.2 and Appendix A2.

Table 2.2. Descriptive statistics of the sample (N=28,967).

	Weighted mean	Standard deviation
Dependent variables		
Participation in AECM	0.09	
Participation in OFS	0.06	
AECM payment (€) (D=1)	7,129.68	6,691.92
OFS payment (€) (D=1)	8,834.07	9,752.82
Independent variables		
Decoupled payment (€/ha)	193.42	379.42
Coupled payment for suckler cows (€)	2,179.01	4,552.01
Land lease (€/ha)	650.72	3,278.06
Fuel price (€/l)	0.63	0.12
Standard gross production (€)	173,838.99	194,712.41
Utilised agricultural area (ha)	89.14	76.73
Labour (Annual Work Unit/ha)	0.24	3.23
Share of rented area	0.73	0.36
Depreciation (€/ha)	2,006.75	34,780.83
Less favoured area (LFA)	0.28	
Age (years)	51.08	9.58
Share of permanent grasslands	0.22	0.31
Grazing livestock density (Livestock Unit/ha)	0.55	1.17
Natura2000 area	0.04	
Certified organic	0.08	
Observed participation in AECM in 2015	0.05	
Observed participation in OFS in 2015	0.04	
Observed participation in AECM at t-1	0.07	
Observed participation in OFS at t-1	0.05	

AECM: Agri-Environment-Climate Measure. OFS: Organic farming support.

Source: 2015-2020 French FADN.

2.2.4. Simulation of CAP budget transfer

We simulate the impact on contract uptake of increasing the budget allocated to AECM and OFS while decreasing direct payments in 2019. On the side of the demand for environmental commitments, it corresponds to a change of demand θ , such that the new budget in 2019 is $B_{19} + \tilde{B}_{19}$. Direct payments distributed to the sample in 2019 (DP_{19}) accounted for 6.7 billion €. The 2019 CAP budget already includes a 7.5% transfer to rural development measures (MAA, 2021b). We first assume an additional transfer of 7.5% to reach 15%, which is the maximum rate allowed under current CAP regulations. The additional budget $\tilde{B}_{19} = \frac{DP_{19}}{1-0.075} * 0.075$ to be allocated is 541 million €. We keep the current budget ratio among the instruments: 53% to AECM ($\tilde{B}_{19}^{AECM} = 286$ million €) and 47% to OFS ($\tilde{B}_{19}^{OFS} = 255$ million €). The budget to

be allocated to sample farms is now $B_{19}^{AECM} + \tilde{B}_{19}^{AECM}=514$ million € and $B_{19}^{OFS} + \tilde{B}_{19}^{OFS}=458$ million €.

In practice, criteria Γ_i prevent some farms from participating in certain measures based on their location. In particular, only farms located in an agri-environment-climate project are eligible to AECM, while maintenance OFS are not available in some regions. Because we do not have enough information in the FADN to identify and exclude non-eligible farms, we assume all the sample becomes eligible. Another (strong) necessary assumption to be allowed to use the estimated model for simulating a change of budget allocation is that the menu of contracts M (technical requirements, area payment) is not affected by a budget transfer. As a result, the estimated effects of farm and farmer characteristics (γ_{it}, k_{it}) and economic context (e_{it}) on the adoption decision and acceptable payments can be considered the same with a different budget allocation.

In the first stage, model estimates are used to predict farm probabilities and acceptable payments for enrolling in AECM (OFS respectively) in 2019 with a decrease of 7.5% of decoupled payments and coupled payments for suckler cows received. In the second stage, farms are ranked according to decreasing predicted probabilities of adopting AECM (OFS respectively). In a third stage, $B_{19}^{AECM} + \tilde{B}_{19}^{AECM}$ ($B_{19}^{OFS} + \tilde{B}_{19}^{OFS}$ respectively) is allocated to farms up to their predicted acceptable payment, starting with the farm with the highest probability to the lowest, until the budget is exhausted.

While keeping the budget ratio among instruments (53% to AECM and 47% to OFS), we also conduct additional simulations to identify the rate of budget transfer that would result in enough conversion OFS uptake to reach the target of 25% of the organic area in France.

2.3. Estimated model of AECM and OFS uptake

To evaluate the model quality, we compare observed participation and farm-level payments in 2016-2019 to predicted probabilities of participation and acceptable payments (Table 2.3). The AECM adoption model tends to underestimate the probability to participate in AECM. Estimated acceptable payments are in the range of the observed farm-level payments of participants on average, although the standard deviation is lower, suggesting the model does not capture well extreme values. The OFS adoption model better captures the probability to

participate, on average for the sample and in particular for maintenance OFS. The acceptable payment of participants is lower than observed farm-level payments on average, particularly for conversion OFS. Similarly to AECM, the model does not capture well the more extreme values. The difference between estimated data and observed data can be partly explained by missing data on exclusion criteria (omitted variable bias). In particular, the absence of information on whether the farm is located in an agri-environment-climate project area may largely explain why the probability of AECM participation is underestimated. Moreover, the difficulty in estimating the AECM acceptable payment of participating farms can be explained by the heterogeneity of AECM payments per hectare and the surfaces enrolled by those farms. Similarly, it seems there are important factors explaining participation in conversion OFS that the model does not capture.

Table 2.3. Comparison between observed and estimated adoption behaviour (N=28,967).

	All sample		Participants	
	Observed	Estimated	Observed	Estimated
Probability to participate in AECM	0.09	0.05		0.49
Probability to participate in OFS	0.06	0.05		0.69
Probability to participate in maintenance OFS	0.05	0.05		0.81
Probability to participate in conversion OFS	0.01	0.00		0.02
AECM acceptable payment (€)		5,613 (3,557)	7,130 (6,692)	7,295 (3,702)
OFS acceptable payment (€)		8,465 (7,617)	8,834 (9,753)	7,722 (6,609)
Maintenance OFS acceptable payment (€)		6,507 (6,413)	8,143 (8,881)	7,511 (6,472)
Conversion OFS acceptable payment (€)		8,632 (7,688)	12,680 (12,963)	9,172 (7,148)

Weighted mean. Standard deviation in parentheses. AECM: Agri-Environment-Climate Measure. OFS: Organic farming support.

Source: own elaboration, using 2015-2020 French FADN.

The marginal effects of the covariates on the latent decision to participate and acceptable payment are presented in Table 2.4, and the coefficients in Appendix A3.

Table 2.4. Generalised Tobit models estimation: marginal effects at the sample mean.

	AECM		OFS	
	Participation decision (D_i^*)	Acceptable payment (P_{ai}) in 1,000€	Participation decision (D_i^*)	Acceptable payment (P_{ai}) in 1,000€
Decoupled payments (100€/ha)	0.000 (0.000)	0.033 ⁺ (0.006)	0.000 ^{***} (0.000)	0.122 ^{***} (0.032)
Coupled payment for suckler cows (1,000€)	0.001 ^{***} (0.001)	0.167 ^{***} (0.033)	-0.001 ^{***} (0.001)	0.029 ^{**} (0.008)
Fuel price (€/l)	0.046 ^{***} (0.043)	1.476 ^{***} (0.290)	0.006 ^{***} (0.011)	-0.161 (0.042)
Land lease (100€/ha)	-0.000 ^{***} (0.000)	0.030 ^{***} (0.006)	-0.000 ^{***} (0.000)	-0.023 ^{***} (0.006)
Standard gross production (100,000€)	-0.007 ^{***} (0.007)	0.053 ^{***} (0.010)	-0.001 ^{***} (0.033)	0.149 ^{***} (0.039)
Labour (AWU/ha)	0.001 ^{***} (0.001)	0.151 ^{***} (0.030)	-0.018 ^{***} (0.007)	0.760 ^{***} (0.198)
Utilised agricultural area (100ha)	0.017 ^{***} (0.016)	1.956 ^{***} (0.384)	0.004 ^{***} (0.007)	6.395 ^{***} (1.667)
Depreciation (10,000€/ha)	-0.000 ^{***} (0.000)	-0.313 ^{***} (0.061)	-0.002 ⁺ (0.003)	-1.849 ^{***} (0.482)
Share of rented land	0.016 ^{***} (0.015)	-0.965 ^{***} (0.190)	0.001 ⁺ (0.002)	0.937 ^{***} (0.244)
Less favoured area	-0.002 ^{**} (0.002)	-0.612 ^{***} (0.120)	0.005 ^{***} (0.009)	-0.062 (0.016)
Cereals, oleaginous, protein crops, other field crops	-0.044 ^{***} (0.042)	0.366 ^{***} (0.072)	0.001 (0.002)	1.019 ^{***} (0.266)
Vegetable gardening, horticulture	-0.105 ^{***} (0.099)	-0.311 (0.061)	0.010 ^{***} (0.018)	0.332 [*] (0.087)
Wine with quality label, other wine	-0.041 ^{***} (0.039)	0.119 (0.023)	-0.002 ^{**} (0.004)	0.757 ^{***} (0.197)
Other permanent crops	-0.048 ^{***} (0.046)	0.657 ^{***} (0.129)	0.032 ^{***} (0.060)	2.838 ^{***} (0.740)
Dairy farming	-0.009 ^{***} (0.009)	1.584 ^{***} (0.311)	0.014 ^{***} (0.027)	2.451 ^{***} (0.639)
Beef farming	0.004 ^{***} (0.004)	0.593 ^{***} (0.116)	0.011 ^{***} (0.020)	-1.179 ^{***} (0.307)
Mixed cattle farming	0.015 ^{***} (0.014)	1.102 ^{***} (0.216)	0.008 ^{***} (0.015)	-0.335 ⁺ (0.087)
Sheep and goat farming	0.014 ^{***} (0.014)	0.530 ^{***} (0.104)	0.003 ^{***} (0.006)	-0.292 [*] (0.076)
Pigs and poultry farming, mixed livestock dominated by granivores	-0.028 ^{***} (0.027)	-0.256 ^{**} (0.050)	0.011 ^{***} (0.020)	0.433 ^{**} (0.113)
Mixed crops farming	-0.043 ^{***} (0.040)	1.010 ^{***} (0.198)	0.016 ^{***} (0.030)	2.411 ^{***} (0.629)
Mixed livestock dominated by grazing livestock	-0.029 ^{***} (0.027)	1.478 ^{***} (0.290)	0.020 ^{***} (0.037)	0.110 (0.029)
Mixed farming: field crops and grazing livestock, other combination of crops and livestock	Baseline			
Age (years)	-0.001 ^{***} (0.001)	0.050 ^{***} (0.010)	-0.001 ^{***} (0.001)	0.008 ^{**} (0.002)
No general education	-0.032 ^{***} (0.030)	-0.620 ^{***} (0.122)	-0.021 ^{***} (0.040)	-0.559 ^{***} (0.146)

Primary school certificate	-0.043 ^{***} (0.041)	-0.959 ^{***} (0.188)	-0.021 ^{***} (0.039)	0.766 ^{***} (0.200)
Secondary education (short)	-0.029 ^{***} (0.027)	-1.435 ^{***} (0.282)	-0.013 ^{***} (0.025)	-0.048 (0.013)
Secondary education (long)	-0.025 ^{***} (0.024)	-1.174 ^{***} (0.230)	-0.011 ^{***} (0.020)	-0.540 ^{***} (0.141)
Non-agricultural higher education	Baseline			
No agricultural education or training ≤120 h	-0.020 ^{***} (0.019)	-2.594 ^{***} (0.509)	0.001 (0.003)	3.207 ^{***} (0.836)
Primary agricultural education	-0.022 ^{***} (0.021)	-3.093 ^{***} (0.607)	-0.000 (0.000)	3.072 ^{***} (0.801)
Secondary agricultural education (short)	-0.024 ^{***} (0.023)	-2.334 ^{***} (0.458)	0.008 ^{***} (0.016)	2.001 ^{***} (0.522)
Secondary agricultural education (long)	-0.021 ^{***} (0.020)	-2.085 ^{***} (0.409)	-0.001 (0.001)	2.864 ^{***} (0.747)
Agricultural higher education (short)	-0.008 ^{***} (0.007)	-1.874 ^{***} (0.368)	0.004 ^{***} (0.007)	2.978 ^{***} (0.776)
Agricultural higher education (long)	Baseline			
Share of permanent grasslands	0.045 ^{***} (0.042)	1.687 ^{***} (0.331)	-0.015 ^{***} (0.029)	-1.847 ^{***} (0.481)
Density of grazing livestock (LU/ha)	-0.002 ^{***} (0.002)	-0.796 ^{***} (0.156)	-0.006 ^{***} (0.011)	0.420 ^{***} (0.110)
Natura	0.037 ^{***} (0.035)	0.425 ^{***} (0.084)	-0.001 ⁺ (0.002)	-2.017 ^{***} (0.526)
Organic certification	0.072 ^{***} (0.068)	0.670 ^{***} (0.132)	0.094 ^{***} (0.176)	0.701 ^{***} (0.183)
Ile de France	0.045 ^{***} (0.042)	1.777 ^{***} (0.349)	0.097 ^{***} (0.180)	12.934 ^{***} (3.373)
Champagne-Ardenne	0.004 (0.004)	-1.055 ^{***} (0.207)	0.062 ^{***} (0.116)	6.301 (1.643)
Picardie	0.036 ^{***} (0.034)	0.543 [*] (0.107)	0.093 ^{***} (0.174)	6.065 (1.581)
Haute-Normandie	-0.013 ^{***} (0.012)	0.180 (0.035)	0.085 ^{***} (0.159)	4.126 (1.076)
Centre	-0.008 ^{**} (0.008)	2.201 ^{***} (0.432)	0.085 ^{***} (0.159)	7.023 ^{***} (1.831)
Basse-Normandie	-0.048 ^{***} (0.045)	1.711 ^{***} (0.336)	0.083 ^{***} (0.155)	4.369 ^{***} (1.139)
Bourgogne	-0.026 ^{***} (0.024)	-0.150 (0.029)	0.108 ^{***} (0.201)	6.476 ^{***} (1.688)
Nord Pas de Calais	0.018 ^{***} (0.017)	-1.143 ^{***} (0.224)	0.089 ^{***} (0.165)	5.618 ^{***} (1.465)
Lorraine	0.000 (0.000)	0.889 ^{***} (0.175)	0.107 ^{***} (0.199)	11.032 ^{***} (2.876)
Alsace	-0.006 ⁺ (0.005)	-1.140 ^{***} (0.224)	0.100 ^{***} (0.186)	6.838 ^{***} (1.783)
Franche-Comté	-0.036 ^{***} (0.034)	-2.961 ^{***} (0.581)	0.091 ^{***} (0.169)	2.804 ^{***} (0.731)
Pays de la Loire	0.008 ^{**} (0.007)	2.886 ^{***} (0.567)	0.104 ^{***} (0.193)	4.681 ^{***} (1.220)
Bretagne	0.055 ^{***} (0.052)	3.077 ^{***} (0.604)	0.074 ^{***} (0.138)	4.674 ^{***} (1.219)
Poitou-Charentes	0.036 ^{***} (0.034)	1.714 ^{***} (0.337)	0.092 ^{***} (0.172)	7.265 ^{***} (1.894)
Aquitaine	-0.019 ^{***} (0.018)	-1.620 ^{***} (0.318)	0.099 ^{***} (0.185)	5.849 ^{***} (1.525)
Midi-Pyrénées	-0.043 ^{***} (0.041)	-2.449 ^{***} (0.481)	0.092 ^{***} (0.171)	6.430 ^{***} (1.676)
Limousin	-0.034 ^{***} (0.032)	-1.563 ^{***} (0.307)	0.097 ^{***} (0.181)	5.154 ^{***} (1.344)

Rhône-Alpes	0.004 ⁺ (0.004)	-1.665 ^{***} (0.327)	0.101 ^{***} (0.188)	5.312 ^{***} (1.385)
Auvergne	-0.027 ^{***} (0.025)	-3.272 ^{***} (0.642)	0.094 ^{***} (0.176)	5.371 ^{***} (1.400)
Languedoc Roussillon	0.013 ^{***} (0.012)	0.101 (0.020)	0.086 ^{***} (0.161)	5.151 ^{***} (1.343)
Provence-Alpes-Côte d'Azur	0.041 ^{***} (0.039)	1.454 ^{***} (0.285)	0.069 ^{***} (0.129)	3.581 ^{***} (0.934)
Corse	Baseline			
Observed participation in AECM in 2015	0.226 ^{***} (0.214)			
Observed participation in OFS at t-1	-0.058 ^{***} (0.055)	-1.377 ^{***} (0.270)		
Observed participation in OFS in 2015			0.060 ^{***} (0.111)	
Observed participation in AECM at t-1			-0.015 ^{***} (0.027)	-0.711 ^{***} (0.185)
2016	-0.046 ^{***} (0.044)	0.065 (0.013)	-0.011 ^{***} (0.021)	-0.597 ^{***} (0.156)
2017	-0.031 ^{***} (0.030)	-0.164 ^{***} (0.032)	-0.012 ^{***} (0.022)	-0.361 ^{***} (0.094)
2018	-0.022 ^{***} (0.021)	0.025 (0.005)	-0.014 ^{***} (0.027)	-0.426 ^{***} (0.111)
2019	Baseline			
ρ	-0.034 ^{***} (0.005)		0.229 ^{***} (0.011)	
σ		5.619 ^{***} (0.013)		7.102 ^{***} (0.021)
Number of observations	28,967	2,442	28,967	1,657
Log likelihood	-506,741		-321,181	
AIC	1,013,733		642,613	
Schwarz criterion	1,015,228		644,109	
Pseudo-R2 (McFadden)	0.237		0.516	

Significance levels: *** p-value <0.001, ** p-value <0.01, * p-value<0.05, + p-value<0.1. Standard errors in parentheses.

AWU : annual work unit. LU: livestock unit. AECM: Agri-Environment-Climate Measure. OFS: Organic farming support.

Source: own elaboration, using 2015-2020 French FADN.

The estimated effects describe the equilibrium of supply and demand of environmental commitments during the 2016-2019 period. The effect of each factor is a net effect and captures both the effect of the demand $\theta(M, B, \Gamma)$ each farm faces (amount of contracts, specific measures and payments each farm is eligible to) and the effect of the characteristics $z_{it} = (\gamma_{it}, k_{it}, e_{it})$ of the supplying farms making them more or less likely to find participation profitable (opportunity costs, fixed costs). The effect of demand on the one hand, and supply on the other hand, cannot be isolated. The correlation estimates ρ of the selection and outcome equations are significant in both models. In particular, *ceteris paribus*, the acceptable payment for adopting AECM decreases with a higher probability of participation, while the acceptable payment for adopting OFS increases with a higher probability of participation.

The effects of covariates on AECM and OFS acceptable payments are difficult to interpret due to the high heterogeneity of contract requirements and payments per hectare, and we can only formulate hypotheses. A positive effect on acceptable payments might reveal either a higher payment per hectare or a higher amount of land to enroll to trigger participation. The estimated marginal effects of the explanatory variables on the adoption decision can more easily be confronted to the literature.

The farm economic context significantly explains the adoption behaviour of farms. Regarding our main covariates of interest, we observe the probability to participate in OFS significantly increases with decoupled payments per hectare and decreases with coupled payments for suckler cows. The marginal effects are low on average (+0.01% per 100€/ha of decoupled payments and -0.1% per 1,000€ coupled payments for suckler cows at the farm level). Regarding AECM, the probability of adoption significantly increases with the amount of coupled payments for suckler cows (+0.1% per 1,000€ of coupled payments for suckler cows at the farm level), while the effect of decoupled payments per hectare is not significant. Both decoupled and coupled direct payments significantly increase the acceptable payment of OFS and AECM. The model suggests the effect of coupled direct payments for suckler cows is stronger on AECM acceptable payments (+167€ per 1,000€) than OFS acceptable payments (+29€ per 1,000€). Decoupled direct payments tend to increase more OFS acceptable payments (+122€ per 100€/ha) than AECM acceptable payments (+33€ per 100€/ha). Our model shows that farmers receiving more direct payments adopt environmental contracts for a higher farm-level payment *ceteris paribus*. As expected, the probability to adopt both schemes increases with the price of fuel (higher relative profitability of adoption of less input-intensive practices).

A higher fuel price also tends to increase AECM acceptable payments, while it does not significantly affect OFS acceptable payments. We find that the effects of the land lease on the adoption decision are similar for AECM and OFS: the higher the cost of land lease per hectare, the lower the probability to participate. This suggests that having access to more productive agricultural land (with higher rent) makes it less economically profitable to dedicate it to environment-friendly production. The effect of direct payments on the OFS adoption decision confirms Jaime et al. (2016), who show that the decoupling of income support has favoured the adoption of organic practices, while coupled income support was a barrier. In the literature, the effect of coupled support on AECM adoption depends on the study (Allaire et al., 2011; Pufahl and Weiss, 2009). Our results confirm those of Pufahl and Weiss (2009) in Germany. We interpret the effect of direct payments on AECM adoption as resulting from the higher set of AECM contracts designed for grazing livestock farming systems, more likely to have suckler cows on farms (MAA, 2020). The effect of the land lease on the adoption decision is also coherent with the literature (Andreoli et al., 2022; Pufahl and Weiss, 2009)

Regarding farm and farmer characteristics, we find that the farm's economic size, UAA, depreciation costs, the share of rented land, farmer's age and general education affect similarly the decision to adopt AECM or OFS. We observe a negative effect of the economic size (standard gross production). It suggests that participation is less profitable for farms with a high potential of production (high opportunity costs to adopt less intensive practices). The bigger the farm UAA, the higher the probability to adopt a contract (economies of scale), while depreciation costs per hectare are an economic barrier. Our model suggests a positive effect of the share of rented land on the probability to adopt an environmental contract. Moreover, younger farmers with high general education are more likely to adopt an environmental contract. These findings are coherent with the literature (Allaire et al., 2011; Andreoli et al., 2022; Chatzimichael et al., 2014; Damianos and Giannakopoulos, 2002; Defrancesco et al., 2018; Giovanopoulou et al., 2011; Jaime et al., 2016; Kallas et al., 2010; Koesling et al., 2008; Läßle and Rensburg, 2011; Mack et al., 2020; McGurk et al., 2020; Pavlis et al., 2016; Pufahl and Weiss, 2009; Uthes and Matzdorf, 2013; Vanslebrouck et al., 2002; Zimmermann and Britz, 2016). Except the effect of economic size, most commonly found to positively affect AECM adoption (Damianos and Giannakopoulos, 2002; Zimmermann and Britz, 2016).

Still regarding farm and farmer characteristics, we identify an opposite effect of labour, LFA support and agricultural education on the AECM and OFS adoption decision. The effect of more labour per hectare, indicating a labour-intensive farm, is positive on the probability to

adopt AECM and negative on the probability to adopt OFS. The effect of agricultural education is also found positive for AECM and negative for OFS while receiving support for LFA decreases the probability to adopt AECM and increases the probability to adopt OFS. Most of those findings are coherent with the literature (Allaire et al., 2011; Andreoli et al., 2022; Damianos and Giannakopoulos, 2002; Ducos et al., 2009; Kallas et al., 2010; Pavlis et al., 2016; Zimmermann and Britz, 2016). However, the effects of labour in our selection equations are opposite to previous results (Defrancesco et al., 2008; Jaime et al., 2016). Another surprising result is the effect of agricultural education on the probability to participate in OFS since Koesling et al. (2008) identified a positive effect on organic farming adoption. The effect of LFA payment on the AECM adoption decision in our model is also not consistent with (Allaire et al., 2011; Unay Gailhard and Bojnec, 2015; Zimmermann and Britz, 2016).

Regarding the farm types, we see that horticulture and market gardening farms (otexe 28, 29) are less likely to adopt AECM relative to the baseline (mixed farming, otexe 83, 84), while mixed cattle and sheep and goat farms are the most likely. For OFS, the highest probability is for arboriculture (otexe 39), while the lowest probability is for vineyards (otexe 37, 38).

The effect of farm characteristics affecting eligibility to specific environmental measures is significant. As expected, the probability to adopt both schemes increases with organic certification (higher relative profitability of adoption of less input-intensive practices). Our model also suggests a negative effect of the grazing livestock density (indicating more intensive production) on the probability to adopt an environmental contract. While the effect of the share of permanent grasslands is found positive for AECM and negative for OFS. Being located in a Natura2000 area increases the probability to adopt AECM while it tends to decrease OFS adoption. We observe that for both AECM and OFS, participation in 2015 significantly increases the probability to participate (+23% for AECM and +6% for OFS). *Ceteris paribus*, we also see that participation in AECM (OFS respectively), significantly decreases if the farm participated in OFS (AECM respectively) the year before. These findings are coherent with the literature (Allaire et al., 2011; Andreoli et al., 2022; Ducos et al., 2009; Laple and Rensburg, 2011; Mack et al., 2020; Pufahl and Weiss, 2009; Zimmermann and Britz, 2016).

Finally, we identify significant year fixed effects. The probability to participate in AECM increases with time. This is expected as farmers see the experience of other farmers, are more aware of the existence of the scheme, and are also more likely to be already enrolled (5-year

contract). We observe a drop in the probability to participate in OFS in 2017, which might result from the fact that some French regions stopped financing maintenance OFS starting from 2017.

2.4. Results of the simulation

The simulated impact on farmers' uptake of environmental contracts of a decrease of an additional 7.5% (reaching the maximum transfer rate of 15% between CAP pillars under current regulations) of direct payments to AECM and OFS in 2019 in France is presented in Table 2.5. Participation in AECM increases from 11% to 24%, and in OFS from 7% to 17%. While the AECM budget more than doubles (+126%), participation and the UAA of participants increase proportionally less (+119% and + 112% respectively), suggesting decreasing returns of budget increase and that participants with the new budget allocation tend to have smaller farms. Regarding OFS, participation and the UAA of participants increase proportionally more than the budget increase (+143% and + 162% respectively), and OFS beneficiaries under the new budget allocation tend to have larger farms. After the budget transfer, 5.7% of the sample is participating in both OFS and AECM, while it was 0.8% in the initial situation. The share of AECM participants with an OFS contract increases from 7.7% to 24.1%, while the share of OFS participants with an AECM increases from 12.1% to 34.3%.

Table 2.5. Simulated impact of a decrease of 7.5% of direct payments in 2019 (N=7,194).

	Baseline			With a budget transfer		
	AECM	OFS	Total	AECM	OFS	Total
Budget (1,000€)	227,862	203,267	431,130	513,981	458,848	972,429
Share of farms (%)	10.8	6.9	16.8	23.7	16.7	34.6
Total UAA of participants (ha)	3,808,678	1,657,456	5,148,400	8,093,439	4,342,287	10,743,844
Share of total UAA (%)	14.5	6.3	19.6	30.8	16.6	41.0
Payment of participants (€)	7,279 (6,768)	10,238 (12,032)	8,843 (9,758)	7,497 (3,610)	9,499 (7,972)	9,699 (7,484)
Acceptable payment (€)	5,843 (3,509)	8,902 (7,573)		5,798 (3,482)	8,872 (7,566)	

Standard deviation in parentheses. AECM: Agri-Environment-Climate Measure. OFS: Organic farming support. UAA: utilised agricultural area.

Source: own elaboration, using 2019 French FADN.

Two combined incentives explain this result. First, there is a direct effect of more budget dedicated to financing environmental commitments. More acceptable payments can be covered and participation becomes profitable for a larger share of farms. This additional budget is taken from 85% of observations receiving direct payments (99% of the UAA) and is redistributed to 29% of observations (34% of the UAA). 22% are new adopters of environmental contracts and 7% are observed participants in 2019 to which the simulation allocates an additional payment (adoption of additional measures). Second, there is an indirect effect of the decrease of direct payments on the acceptable payments triggering participation. The average decrease of acceptable payment per farm is 30€ for OFS, and 45€ for AECM. Those “savings” contribute to financing the participation of even more farms.

We identify a differentiated impact according to the type of farm. The farms losing the most income from lower direct payments are specialised in mixed cattle (-3,115 €/farm on average in otexe 47) and in mixed farming with field crops and grazing livestock (-3,015€/farm on average in otexe 83). The less affected farms are specialised in horticulture (-56€/farm on average in otexe 29) and quality wine (-205€/farm on average in otexe 37). On the one hand, the reorientation of the budget towards environmental contracts particularly incentivises farms specialised in grazing livestock to contract AECM (otexe 45, 46, 47, 48 and 83) (Table 2.6). This effect seems driven by the decrease in acceptable payments associated with lower coupled payments for suckler cows. In particular, AECM acceptable payments decrease the most for farms specialised in beef (-186€/farm on average in otexe 46) and mixed cattle (-125€/farm on average in otexe 47). On the other hand, the reorientation of the budget particularly incentivises farms specialised in permanent crops, dairy, pigs and poultry or mixed farming with field crops and grazing livestock to contract OFS (otexe 39, 45, 50, 83). For farms specialised in permanent crops or mixed farming with field crops and grazing livestock (otexe 39, 83), this effect seems driven by their highest probability to adopt OFS.

Table 2.6. Change of allocation of environmental incentives among farm types with an additional transfer of 7.5% of direct payments budget to reach 15% in 2019 (%) (N=7,194).

Technical orientation	AECM - baseline	AECM – budget transfer	OFS - baseline	OFS - budget transfer
15	16.69	8.07	16.46	17.06
16	3.96	1.75	6.35	4.33
28	0.74	0.20	4.93	4.53
29	0.00	0.00	1.76	1.94
37	3.75	3.60	14.79	11.14
38	0.75	0.28	0.11	0.52
39	1.16	0.73	6.35	8.95
45	17.67	21.74	18.08	20.85
46	24.87	27.38	7.34	7.98
47	4.79	7.10	1.39	0.82
48	6.25	8.92	5.57	3.22
50	2.60	1.73	2.48	5.01
61	0.78	0.21	2.79	2.90
73	0.18	0.55	1.92	1.63
74	1.09	0.66	1.31	1.21
83	10.37	13.23	3.66	4.66
84	4.31	3.86	4.71	3.25

AECM: Agri-Environment-Climate Measure. OFS: Organic farming support.

Source: own elaboration, using 2019 French FADN.

The outputs of the simulations under different budget transfer scenarios, and in particular the resulting share of organic UAA are presented in Table 2.7. In 2019, almost 9% of the UAA was organic. In the first scenario of 15% of transfer between the two pillars (7.5%+7.5%), the uptake of conversion OFS is such that that the organic UAA more than doubles. To reach 25% of organic UAA, our model suggests a transfer rate of 15.5% (7.5%+8%) if OFS payments are restricted to farms undertaking a conversion to organic farming, and 21% (7.5+13.5%) if both certified and non-certified farms remain eligible.

Table 2.7. Impact of a budget transfer in 2019 under several transfer scenarios (N=7,194).

Direct payments transfer (%)	15		15.5	21
Environmental scheme	AECM	OFS	Conversion OFS	OFS
Budget (million€)	514.0	458.8	475.5	663.7
Share of farms (%)	23.7	16.7	14.5	23.3
Share of total UAA (%)	30.8	16.6	18.5	24.5
Acceptable payment (€)	5,798	8,872	8,751	8,848
Total organic UAA (%)	17.8		25.9	25.4

AECM: Agri-Environment-Climate Measure. OFS: Organic farming support. UAA: utilised agricultural area. Budget allocation assumption: 53% AECM/47% OFS.

Source: own elaboration, using 2019 French FADN.

2.5. Discussion and concluding remarks

AECM and OFS are currently the most ambitious environmental contracts in the CAP. We evaluated the potential to upscale their adoption without increasing the CAP budget, by transferring part of the budget for direct payments with little environmental conditionality to fund additional environmental contracts in France in 2019. Our findings suggest this mechanism successfully increases participation by combining two incentives. First, we identify a direct effect of more public money dedicated to financing environmental commitments. Second, we identify an indirect effect on farmers' behaviour of receiving lower direct payments, which tends to decrease the farm-level acceptable payment triggering their decision to participate, making even more money available to finance more environmental commitments.

This study proposes a methodological approach to model farmers' behaviour at the national scale regarding the uptake of environmental commitments within the CAP, applied using FADN data available in all EU countries. We used it to evaluate ex-ante the impact of CAP budget allocation changes on the adoption of environmental contracts while capturing the effect of income support instruments on this adoption behaviour. The results can be analysed at the farm level, highlighting a differentiated impact according to farm specialisation. Nevertheless, simulation results need to be interpreted with care, as they depend on the quality of the adoption model estimated. Our model tends to underestimate the probabilities of adoption and acceptable payments compared with observed data, in particular for conversion OFS. It can be explained by insufficient information in the FADN to precisely capture contract eligibility, and the

characteristics of the measures adopted by farmers. Not controlling for the payment per hectare and the surfaces enrolled for each type of measure remains an important limit of this work, as they represent sources of heterogeneity across farms that we do not capture. To improve this aspect, one could complexify the estimation procedure and control for individual fixed effects or lagged participation. Another possibility is to merge the FADN sample with the dataset on participants to rural development measures collected each year for the Annual implementation report (RAMO) and collect some of the missing information (surfaces under contract, type of measure adopted by each farm, municipalities eligible to environmental contracts). A second important limit to the study is that the reliability of the results decreases for higher rates of reduction of direct payment since the simulation uses *marginal* effects of direct payments on contract adoption.

Nevertheless, our empirical findings support the relevance of decreasing untargeted payments and increasing targeted payments for the delivery of environmental public goods in the CAP. Previous evaluation of the reorientation of 15% of direct payments towards rural development measures in the EU28 and in Germany with the Common Agricultural Policy Regionalised Impact partial equilibrium model identified marginal impacts on environmental indicators (Schroeder, 2021; Schroeder et al., 2015). Another study in Greece suggests 50% transfer would lead to an extensification of farming practices and improve water quality and biodiversity (Giannakis et al., 2014). While a transfer from direct payments to environmental incentives with the current regulation (maximum 15%) is unlikely to be sufficient to achieve the Farm to Fork target of 25% of organic land, our results suggest it can significantly contribute to it. The French government decided to limit eligibility to OFS to non-certified farms. Our simulations show this targeting facilitates the conversion of more land to organic. However, removing maintenance OFS can hinder the Green Deal objective in the long term if keeping organic practices is not profitable through the market. Finally, other levers can be applied such as improving contract design to increase attractiveness and environmental effectiveness, and supporting the development of the organic market. Moreover, the introduction of eco schemes in the first pillar of the CAP, financed with 25% of the direct payments envelope might trigger more voluntary adoption and significant environmental additionality.

Chapter 3. Payments for environmental services with ecological thresholds: farmers' preferences for a sponsorship bonus

In the two following chapters, I move my focus to the design of payment mechanisms of PES.

One of the main limits of the PES developed since the early 1990s (ex: AEEM), is their high inefficiency when it comes to increasing the provision of public goods with threshold effects (water quality, biodiversity...). In particular, the dominating action-based payment conditionality based on the prescription of on-farm practices to individual farmers regardless of what is done on neighbouring farms seems inadequate to address their underprovision. In this chapter, I study the introduction of a payment mechanism combining action-based conditionality with a bonus for favouring a landscape approach. In particular, I propose a sponsorship bonus as a top-up to an individual per-hectare payment to promote higher participation in the target area. In addition, I do not constraint the PES to be funded by a public financing mechanism, and introduce the possibility for higher payments than currently proposed with AEEM. I apply a choice experiment (CE) to measure ex-ante farmers' preferences for such a bonus mechanism in a PES aiming at improving the water quality of rivers in northwest France.

This chapter was co-authored with Carole Ropars-Collet (Institut Agro, SMART), Alice Issanchou (INRAE, SMART) and Pierre Dupraz (INRAE, SMART), and involved the following individual contributions: Fanny Le Gloux: conceptualisation, investigation, methodology, data curation, formal analysis, original draft; Carole Ropars-Collet: conceptualisation, methodology, validation, writing review and editing; Alice Issanchou: conceptualisation, validation, writing review and editing; Pierre Dupraz: conceptualisation, supervision, validation. Preliminary versions were presented at the 96th Annual Conference of The Agricultural Economics Society (4th-6th April 2022 in Leuven, Belgium), the 4th Annual Meeting of the Research Network on Economic Experiments for the Common Agricultural Policy (8th-9th June 2022 in Uppsala, Sweden), and the 9th PhD Workshop of the European Association of Agricultural Economists (22nd-24th June 2022 in Parma, Italy). The analyses also contributed to deliverable D3.2 (D'Alberto et al., 2022) of the CONSOLE project (<https://console-project.eu/>), and to an article for stakeholders of the French agricultural sector

(Le Gloux et al., 2022). This present version has been submitted to the Journal of Environmental Planning and Management in November 2022 and is under revision.

3.1. Introduction

Payments for environmental services (PES) are initiatives supporting farmers' voluntary interventions contributing to the preservation of ecological functions (Duval et al., 2016; Sven Wunder, 2015). They emerged in the early 1990s, in response to the growing awareness of the value and shortage of agri-environment-climate public goods. In the European Union (EU), the most widely implemented PES are the agri-environmental measures, now called agri-environment-climate measures (AECM), of the common agricultural policy (CAP). Over the past decades, the low environmental additionality, participation rates and cost-effectiveness of AECM have been highlighted in the literature, in particular, due to underfunded and poorly designed measures (Cullen et al., 2018; Dupraz and Pech, 2007; Espinosa-Goded et al., 2013; Zavalloni et al., 2019). Dedicated PES involving other contractual arrangements and financial contributors are also implemented on a smaller scale (Heinz, 2008). Examples include schemes funded by water bottlers such as the Nestlé Waters, or by municipalities such as the water authorities of Munich and New York City (Déprés et al., 2008; Grolleau and McCann, 2012).

Designing efficient payment mechanisms for public good provision is a challenge that often involves trade-offs between environmental ambition and large acceptance by farmers. Conditionality rules must define environmental services with sufficient effort to reach the environmental objective(s) while remaining attractive enough to ensure significant participation on enough farmland. When the objective is to improve water quality or biodiversity, high participation and spatial continuity of environmental commitments at the landscape scale are necessary to observe environmental improvements (Dupraz et al., 2009). Developing instruments favouring collaboration among land managers, coordination of actions and high uptake within the same area are promising ways to increase the environmental effectiveness of farmers' environmental services, as well as the cost-effectiveness of the payment. In addition to supporting the passing of ecological thresholds, collective approaches provide other advantages, such as fewer transaction costs for financial contributors, and the building of social capital for farmers (Kuhfuss et al., 2016; Lefebvre et al., 2015; Pretty, 2003).

Collective approaches can take different forms of PES contractual arrangements and payment conditionality (Kuhfuss et al., 2019; Uetake, 2013). Some involve a collective payment. In this case, the contracting party receiving the payment and meeting the requirements is a group of farmers, which distributes the amount to participants according to the rules defined by the collective. The Netherlands provide a large number of examples of successful collective

AECM, in which participants are local groups of farmers organised in environmental cooperatives (Franks, 2011). Cases from other EU countries are scarce. One can cite the collective AECM for preserving the European Hamster habitats in France (Eichhorn et al., 2022). Other approaches are based on individual contracting, but the distribution of the payment is conditional to the achievement of a landscape-scale objective (minimum participation or land enrolment, reaching an environmental goal...), or of a collaborative action (coordination of management practices, agglomeration of the plots enrolled...). These conditionality rules can apply to all or part of the payment. In the latter case, the collective component of the contract takes the form of a conditional “reward” or “bonus”. An example of such a payment mechanism is the Swiss network bonus (agglomeration bonus) (Krämer and Wätzold, 2018).

The literature suggests farmers are reluctant when collective requirements are conditioning the full payment, but favourable to a reward conditioned to collective action on top of an individual payment (Villanueva et al. 2017; Ben-Othmen and Ostapchuk 2019; Le Coent, Préget, and Thoyer 2017; Villamayor-Tomas, Sagebiel, and Olschewski 2019; Kuhfuss et al. 2016). Villanueva et al., (2015; 2017) show that individual contracting tends to be preferred to collective contracting of a minimum number of farms from the same municipality, especially among older farmers with little experience in participating in cooperatives. Interestingly, Ben-Othmen and Ostapchuk (2019) find the opposite result, with positive preferences for collective contracting, but the threshold number was slightly lower (3 farms from the same municipality against 5 in (Villanueva et al. 2015)). Both case studies included prior information that farmers would be left free to form a group with whom they trust the most, and that only free-riders would be sanctioned in case of non-compliance with management requirements. A key factor of collective AECM acceptance is well-defined group governance and monitoring, which is often emphasized by researchers studying successful Dutch case studies of environmental cooperatives (Franks 2011; Uetake 2014; Barghusen et al. 2021), or more generally collective management of natural resources (Ostrom 2002; Kerr, Vardhan, and Jindal 2014). Le Coent et al. (2017) looked at farmers’ preferences for biodiversity offsets with the full payment conditioned to a minimum of 20% of participation of farmers from the area. They found that farmers anticipate transaction costs for reaching the participation threshold and prefer contracts without it. Another study measuring preferences for an AECM requiring the coordination of the location of tree planting with neighbouring farms also concluded that farmers were reluctant to the collective approach due to transaction costs and beliefs that other farmers would not be willing to cooperate (Villamayor-Tomas, Sagebiel, and Olschewski 2019). However, they

identified a peer effect, with the finding that farmers were more likely to choose an agri-environmental measure recommended by other farmers. When it comes to collective bonus options, a study by Kuhfuss et al. (2016) reveals positive preferences for a conditional bonus if at least 50% of the eligible area is enrolled in the scheme after five years.

Apart from this last study by Kuhfuss et al. (2016) among vine growers, there is still little evidence of farmers' attitudes towards mixed-payment mechanisms promoting collective approaches. Further analyses would confirm or nuance the acceptability of these nudges in other contexts, and provide recommendations for designing successful schemes. This present study aims at providing new elements on the acceptability among farmers of a collective component in PES, designed to meet high participation rates and environmental efforts.

We develop a choice experiment (CE) to measure preferences for a contract targeting the improvement of river ecological quality in three regions of north-western France, characterized by the predominance of livestock farming and concerns over too much release of excess nitrogen and phosphorous into water bodies. CE are particularly relevant to elicit preferences for specific contract characteristics that do not yet exist (Louviere et al., 2000). Two types of bonuses are tested to explore new elements in the design of payment mechanisms: an individual bonus for sponsoring a peer, and a sponsorship bonus combined with a collective environmental result bonus distributed equally to all participants. Another contribution of the study is to offer payment levels which are higher than the range of current AES. By doing so, we consider the possibility for other contributors than public authorities to finance the PES, and we capture farmers' willingness to accept (WTA) beyond income foregone and additional costs.

The paper is organised as follows. Section 3.2 introduces the choice modelling and experimental design. Section 3.3 describes the survey data. Section 3.4 presents and discusses the results. Section 3.5 provides some concluding remarks and policy recommendations.

3.2. Method

3.2.1. Discrete choice experiment approach

A CE is a survey-based method to elicit the stated preferences of individuals. Respondents are successively asked to choose their preferred option among a small number of hypothetical alternatives, which differ according to several levels of attributes. CE techniques are based on Lancaster's theory that consumption decisions are determined by the utility derived from the attributes of the good being consumed (Lancaster, 1966) and the random utility theory decomposes utility into a deterministic part and a random part (McFadden, 1974). They are particularly useful to estimate ex-ante the marginal utility of different characteristics of policy design. The application of CE methods already provided a lot of useful policy recommendations for agri-environmental contracts design, for instance regarding farmers' preferences for contract length (Bougherara and Ducos, 2006; Christensen et al., 2011; Gruau et al., 2019; Latacz-Lohmann and Breustedt, 2019; Ruto and Garrod, 2009), payment sequences (Bougherara et al., 2021) and conditional bonuses (Kuhfuss et al., 2016; Vaissière et al., 2018).

3.2.2. Model specification

Under the random utility theory, the utility U_{njt} that individual n obtains from choosing alternative j out of J alternatives in the choice set t out of a series of T choice sets, is made of an observed component V_{njt} (deterministic part) and a stochastic error term ε_{njt} (random part).

$$U_{njt} = V_{njt} + \varepsilon_{njt} \quad (3.1)$$

We assume individual n chooses alternative j if and only if that alternative maximises his or her utility amongst all alternatives in choice set t . The probability that farmer n chooses alternative j is:

$$P_{njt} = Prob(V_{njt} + \varepsilon_{njt} > V_{nit} + \varepsilon_{nit}) = Prob(\varepsilon_{njt} - \varepsilon_{nit} > V_{nit} - V_{njt}) \quad \forall i \neq j \quad (3.2)$$

The deterministic part of the utility function is typically specified to be linear in parameters. The error terms are assumed to follow the Gumbel Type-1 extreme-value distribution (McFadden, 1974), such that a logit model can be applied to estimate the parameters.

Under the conditional logit (CL) model, the β coefficients representing respondents' preferences for the attribute levels X_{njt} are constant across individuals (homogeneous preferences), and the error terms are assumed independent and identically distributed across individuals and alternatives (3.3). It implies that the ratio of choice probabilities for any two alternatives is independent of the attribute levels of a third alternative in the choice set, and is known as the independence of irrelevant alternatives assumption (IIA).

$$P_{njt} = Prob(\varepsilon_{njt} - \varepsilon_{nit} > \beta(X_{nit} - X_{njt})) \forall i \neq j \quad (3.3)$$

The Hausman test allows checking the independence of irrelevant alternatives (IIA) and validate the CL model specification (Hausman and McFadden, 1984). To relax the IIA assumption and account for taste heterogeneity across farmers or groups of farmers, the mixed logit (ML) (3.4) or latent class (LC) (3.5) models are applied (Greene and Hensher, 2003).

$$P_{njt} = Prob(\varepsilon_{njt} - \varepsilon_{nit} > \beta_n(X_{nit} - X_{njt})) \forall i \neq j \quad (3.4)$$

$$P_{njt|q} = Prob(\varepsilon_{njt} - \varepsilon_{nit} > \beta_q(X_{nit} - X_{njt}) | class q) \forall i \neq j \quad (3.5)$$

Both the ML model and the LC model keep the assumption that error terms are independent and identically Gumbel Type-1 distributed, but allow preference parameters to vary. The ML model specifies a continuous distribution of the coefficients such that preferences vary randomly across individuals. The LC model specifies a discrete distribution to the coefficients and relies on the definition of classes of individuals. While preferences are heterogeneous across the different classes, individuals of the same class are assumed homogeneous.

A monetary attribute is included (ex: individual payment of a PES contract) to evaluate the WTA of respondents for each specific attribute level. An estimate of the average WTA for each attribute X_{njt} is obtained from the ratio of the coefficient of the corresponding attribute β_X and the payment coefficient $\beta_{payment}$ (3.6) (Mariel et al., 2021). WTA_X is the average annual payment per hectare a farmer requires to accept a contract for which the level of attribute X is higher by one unit.

$$WTA_X = \frac{-\beta_X}{\beta_{payment}} \quad (3.6)$$

3.2.3. Experimental design

A CE was conducted to measure farmers' preferences for a 5-year contract for which participants would enroll all their farmland, targeting the improvement of the water quality of rivers in northwestern France. The regions Brittany, Pays de la Loire, and most of the Normandy region are classified as Nitrate Vulnerable Zones under the Nitrates Directive (MTE and MASA, 2011). While the Water Framework Directive targets good chemical and ecological status of European waters by 2027 (EU, 2000), only 13% of surface waters have a good ecological status in Pays de la Loire, 32% in Brittany and 29% in eastern Normandy (Agence de l'eau Loire-Bretagne, 2020a, 2020b; Agence de l'eau Seine-Normandie, 2018). Locally, some areas are particularly concerning, such as eastern Brittany (Ille-et-Vilaine department) with only 2% of surface waters with good ecological status (Département d'Ille-et-Vilaine, 2022).

The contracts proposed in the CE are characterized by (1) management requirements defining the environmental services to be delivered by farmers, (2) a per-hectare payment distributed to farmers individually on an annual basis if they comply with management requirements and (3) a bonus option (Table 3.1).

Table 3.1. Attributes and attribute levels in the choice experiment.

Attribute	Description	Levels
Soil cover	Average agricultural soil coverage throughout the year at the farm level (no bare soil, starting from seeding)	85% 90% 95%
Hedgerows	Average density of anti-erosion multi-species multilayer hedgerows at the farm level	20m/ha 60m/ha 100m/ha
Payment	Per-hectare individual annual payment	150€/ha 300€/ha 450€/ha 600€/ha
Bonus	Bonuses conditioned to a collective action : A fixed individual sponsorship bonus of 450€ the farmer receives each time he convinces a peer into entering the scheme ; A collective result bonus of 50€/ha distributed to all participants if the river's status reaches a higher step of the water quality scale	None Sponsorship bonus Sponsorship bonus + collective result bonus

Source: own elaboration.









Evidence shows that hedge networks in agricultural landscapes such as bocage, act as buffer zones and erosion barriers preventing runoffs in water catchments, in synergy with many other ecological side-benefits (Burel and Baudry, 1995; Caubel-Forget et al., 2001; Merot, 1999). Avoiding long periods of bare soil, in particular in winter, also contributes to limiting soil erosion and runoffs (Souchère et al., 2003). The choice of management and individual per-hectare payment attribute levels was based on evidence from a study undertaken in a similar environmental context in Brittany (Gruau et al., 2019). In particular, their results show that payments of 400€/ha or less, restricts the adoption of PES with ambitious levels of management requirements because some farmers have a higher willingness to accept that cannot be met with this payment range. In France, the 5-year AECM contributing to water quality is typically in a range between 70€ and 350€/ha/year, based on an estimation of average opportunity costs (MASA, 2022). In our CE, we include individual per-hectare payment levels higher than typical AECM, to include the possibility that other contributors than governmental authorities finance all or part of the payment. The degradation of rivers' chemical and ecological quality does not only contribute to biodiversity loss but also increases the costs of water treatment for securing drinking water quality. Protecting water resources is of interest to many local stakeholders

(water catchment bodies, inhabitants, companies, and municipalities...). Real-life contractual arrangements for reducing costs of drinking water depollution show that big municipalities such as Munich have been paying farmers up to 280€/ha/year (Déprés et al., 2008), while the private company Nestlé Waters spent around 230€/ha/year to secure their brand Vittel (Perrot-Maitre, 2006). Inhabitants of water catchment areas also exhibit a willingness to pay for reaching a good ecological status (40€/household/year estimated in Normandy), derived from the value they attach to multiple local benefits (recreational use, drinking water, floods prevention, landscape...) (Poirier and Fleuret, 2015). Their role as PES scheme financers would better capture society's willingness to pay and cover farmers' WTA beyond compensation for foregone profits. WTA includes uncertainty and factors that are not necessarily technical barriers, such as transaction costs or social capital (Espinosa-Goded et al., 2013).

The bonus option levels were defined together with stakeholders involved in the development of experimental PES in the study area. A sponsorship bonus, suggested by a group of farmers from the Seiche Valley (Ille-et-Vilaine, Brittany) (Bailly et al., 2022), is introduced and takes the form of an individual reward for convincing a peer farmer from the water catchment area to enter the PES scheme. A farmer would receive a one-time 450€ per new peer sponsored. Each farmer can be sponsored only once. For the parties financing the PES scheme, offering the sponsorship bonus is an opportunity to increase participation at the water catchment scale while benefiting from the peer effect (communication on the PES, knowledge spillover...). However, sponsoring peers induces new transaction costs for farmers (social commitments, time). A second level of bonus option introduces an additional reward of 50€/ha, distributed to all participants if a collective environmental result is obtained. The environmental result is a higher step for the river's status on the water quality scale. This option aims at encouraging collaborative effort to reach a landscape objective and increase even further the environmental effectiveness of the scheme. Testing the combined introduction of a sponsorship and a collective environmental result bonus is particularly interesting to see if rewarding a collective environmental result affects the WTA of the bonus option relative to the sponsorship bonus only. The interest of the combined bonuses lies in increasing the incentive for reaching a critical mass of participants, and in particular where environmental effort contributes the most to water quality (big farms or located in the upstream of the river). Moreover, the positive effect of the sponsorship bonus on participation stops once all farmers from the eligible area have entered the scheme. The result-based collective bonus would maintain the incentive to pursue coordinated efforts towards the environmental objective. A fourth level with the collective

result bonus without the individual sponsorship bonus was not included in the experimental design to limit the number of choice cards and minimum number of respondents required.

Choice sets include two contract alternatives and the *status quo* (option to opt-out and choose none of the contracts). They were designed by combining the different attribute levels (see Figure 3.1 for an example of a choice card). A d-efficient design of 36 choice sets to be divided into 4 blocks of 9 choice cards was constructed (Appendix A4).

Attribute	Contract A	Contract B	Status-quo
Hedgerows	100 m/ha 	60 m/ha 	I prefer to keep my current practices
Soil cover			
Payment	300€/ha 	150€/ha 	
Bonus	None	Sponsorship bonus : 450€/sponsored peer  + Collective bonus : 50€/ha 	

Source: own elaboration.

Figure 3.1. Example of choice set of the choice experiment.

For the econometric analyses, the individual per-hectare payment attribute (*PAYMENT*) is coded as a continuous variable, and the bonus option levels (*BONUS sponsorship*, *BONUS sponsorship/collective result*) as dummy variables. We compare continuous and effects coding for the management attributes (*COVER*, *HEDGEROWS*) to choose the best specification (Mariel et al., 2021). We define an alternative specific constant controlling for the status-quo alternative (*ASC_{sq}*). The attribute levels of the status quo alternative are set at 0 for the individual per-

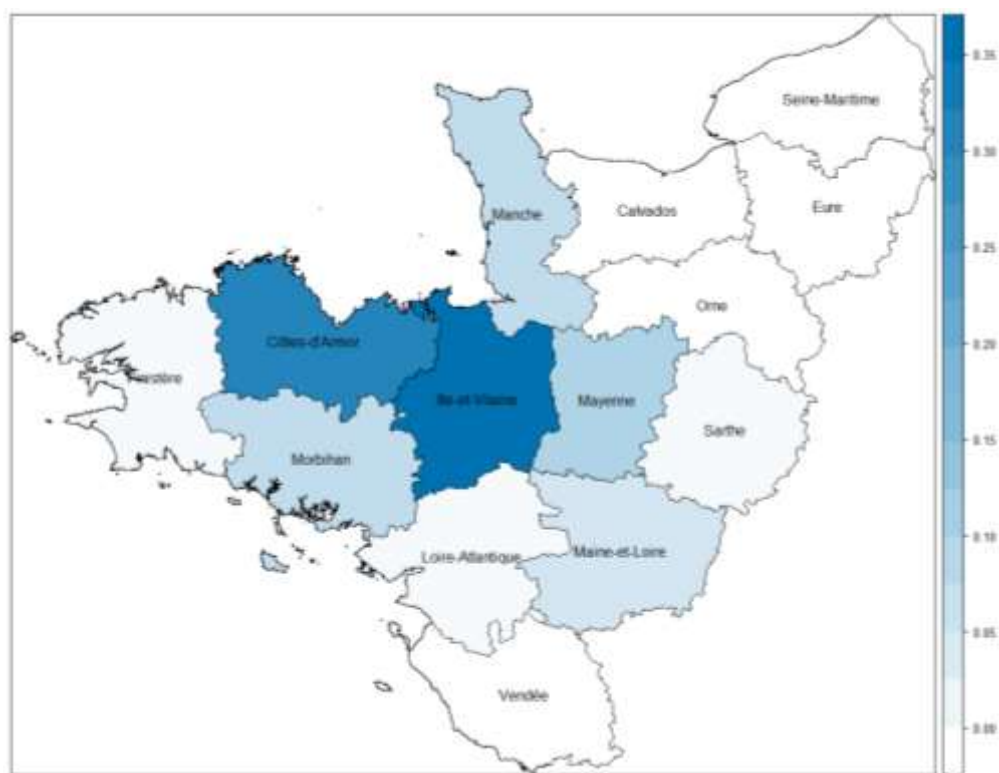
hectare payment and bonus option attributes. For the management attributes, we compare a status quo level fixed at 0 and at the farm's current values (individual status quo) to identify the best specification. We conduct the analyses using the Apollo package on R (version 0.2.7). In particular, we use the `apollo_searchStart` function to test a large range of starting values for the model parameters and keep the best candidate for the estimation (Hess and Palma, 2022).

3.2.4. Survey structure

The CE was included as a section of a pan-EU survey on the acceptability of agri-environmental-climate contract solutions, conducted in France among farmers located in Brittany, Normandy and Pays de La Loire. Voluntary farmers were contacted to organise a face-to-face interview after being recommended by intermediaries (farmers unions, organisations of milk producers, and farmers' associations...). The first section of the survey included general information on farmer and farm characteristics and the second section questions to evaluate the impact of contract characteristics on the willingness to adopt contractual solutions. For instance, farmers were asked to state on a scale from 1 to 5 how much would the possibility to receive a common payment to be distributed among participants increase or decrease their willingness to participate. We use this information as an indicator of attitude towards collective approaches. In the third section dedicated to the CE, respondents were introduced to the context, objective and rules of the game of the CE as well as the contract parameters (those fixed and those varying from one alternative to another). Preliminary questions were included to help the respondents estimating their current levels of management requirements (individual *status quo*). The current soil cover duration was calculated from the stated hectares of permanent grasslands, arable crops, permanent crops and total utilised agricultural area (UAA), as well as the average number of days with bare soil on arable lands and proportion of grass cover on the permanent crops surfaces (bare soil stopping after seeding). The current hedgerows density was calculated from the total UAA and total meters of multispecies multilayer hedgerows currently on the farmland. Farmers were then asked 9 times to choose the preferred option among 2 contract alternatives and the status-quo.

3.3. Data

The interviews were conducted with 130 farmers between April and July 2021. Among them, 97 farms are located in Brittany, 23 in Pays de la Loire, and 10 in Normandy (Figure 3.2).



Departments of Brittany: Finistère, Côtes-d’Armor, Ille-et-Vilaine, Morbihan.

Departments of Normandy: Manche, Calvados, Orne, Eure.

Departments of Pays de la Loire: Mayenne, Sarthe, Loire-Atlantique, Maine-et-Loire, Vendée.

Source: own elaboration.

Figure 3.2. Distribution of the sampled farms in the surveyed regions (ratio).

Descriptive statistics of the sample are provided in Table 3.2. A comparison with data from the agricultural census and the farm accountancy data network for the surveyed regions shows that our sample presents some biases. This bias can be explained by the non-random sampling procedure respecting the data protection policy, which involved a preliminary selection of volunteers by intermediaries. The average UAA of the sample is 100ha (median of 85ha), and half of the respondents are dairy farmers. The sample is representative of the average UAA of

farms of medium and large economic size, but over-represents the share of dairy and organic farms, and under-represents farms specialised in field crops (Agreste, 2021). While the share of young farmers below 40 years old is representative of the farming population, farmers between 40 and 50 years old are over-represented (DRAAF Bretagne, 2022; DRAAF Normandie, 2022; DRAAF Pays de la Loire, 2021). The sample is also biased towards highly educated and male farmers.

Table 3.2. Descriptive statistics of the sample (N=130).

Variable	Mean
Utilised agricultural area (ha)	100.3 (64.3)
Rented	0.72 (0.28)
Permanent grasslands (4 n.a)	0.36 (0.32)
Arable land (4 n.a)	0.62 (0.32)
Dairy	0.51
Beef	0.09
Granivores	0.08
Field crops	0.06
Certified organic	0.39
Participating in agri-environmental schemes in 2020	0.41
Female	0.13
Higher education	0.63
Below 50 years old	0.55
Below 40 years old	0.22
Stop managing farm activities in 5 years or less	0.20
Farming is less than 70% of household gross revenue	0.11
In a farmer organisation	0.62
In an environmental organisation	0.17
Soil cover (%) (4 n.a)	94.9 (7.1)
Hedgerows (m/ha) (10 n.a)	87.8 (73.7)

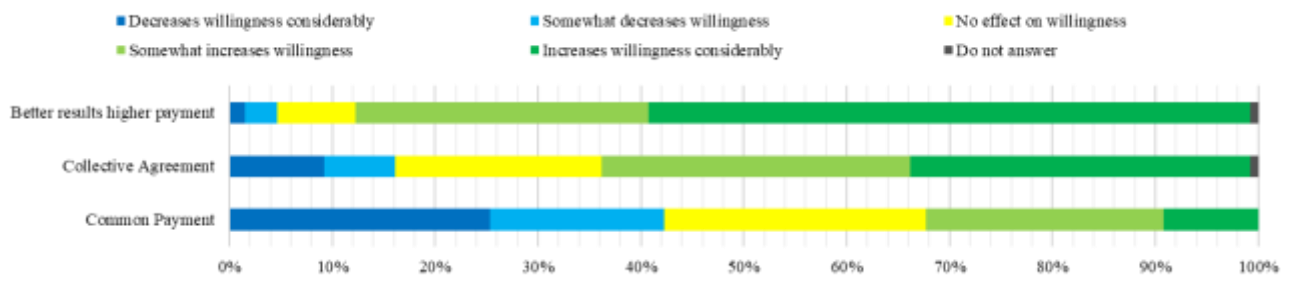
Standard deviation in parantheses. n.a: not answered.

Source: own elaboration.

The current levels of anti-erosion multispecies multilayer hedgerows density and soil cover duration estimated for the sample are particularly high for the surveyed area, with many farms already fulfilling the highest levels of the hypothetical contract's requirements. Farmers stated few days of bare soil for their arable land (25 days on average), and 88 m/ha of multispecies

multilayer hedgerows on average at the farm level. All types of hedgerows considered (including monospecies or monolayer), the observed average density is 49 m/ha in Normandy, 48 m/ha in Brittany, and 55 m/ha in Pays de la Loire (Mission Bocage, 2011; Simon et al., 2019, 2018).

Regarding PES characteristics, most of the respondents (89%) have a positive attitude towards higher payments for higher environmental results (Figure 3.3). Collective approaches are less popular, with 64% of respondents declaring the possibility to agree collectively at the landscape-level would increase their willingness to adopt a contract, and 32% for receiving a common payment to be distributed among participating farmers.



Survey question: how much would the following contract characteristics increase or decrease your willingness to enroll?

¹ The payment gets higher, the better your environmental results are.

² You can collectively agree on environmental targets and measures at the landscape-level together with other land managers.

³ You and other land managers receive a common payment. You jointly agree on the distribution of the payment.

Source: own elaboration, based on CONSOLE landowner survey results in France.

Figure 3.3. Stated effect of contract design characteristics on willingness to adopt.

Among the 130 respondents, five systematically chose the status quo option in the CE. We consider them as protest respondents and excluded their answers from the sample for the following econometric analyses.

3.4. Results

As a baseline, we estimate a CL model with attribute levels and the ASC_{sq} as explanatory variables (Equation (3.3)) (Table 3.3). Three specifications are tested: continuous coding of management attributes with status quo levels fixed at the current farm level stated in the survey (CL1), continuous coding of management attributes with status quo levels fixed at 0 (CL2), and effects coding of management attributes with status quo levels necessarily fixed at 0 (CL3). They provide similar estimates, in particular for the individual per-hectare payment and bonus attributes. Effects coding reveals nonlinear preferences for hedgerows management requirements. We decide to keep the first specification with the best goodness of fit measures (AIC, BIC). By capturing the individual status quo levels, specification CL1 better measures preferences for the ASC_{sq} , while limiting the number of variables in the model.

Table 3.3. Conditional Logit estimations.

Specification	CL1	CL2	CL3
<i>PAYMENT</i>	0.004 ^{***} (0.000)	0.004 ^{***} (0.000)	0.004 ^{***} (0.000)
<i>COVER</i>	0.007 (0.016)	0.021 ⁺ (0.013)	
<i>COVER</i> - 90%			0.077 (0.066)
<i>COVER</i> - 95%			0.070 (0.073)
<i>HEDGEROWS</i>	-0.006 ^{**} (0.002)	-0.004 [*] (0.003)	
<i>HEDGEROWS</i> – 60m/ha			0.134 [*] (0.068)
<i>HEDGEROWS</i> – 100m/ha			-0.246 [*] (0.108)
<i>BONUS</i> <i>sponsorship</i>	0.419 ^{***} (0.127)	0.409 ^{***} (0.118)	0.426 ^{***} (0.124)
<i>BONUS</i> <i>sponsorship/collective result</i>	0.265 [*] (0.138)	0.256 [*] (0.129)	0.277 [*] (0.131)
<i>ASC</i> _{sq}	0.653 ^{**} (0.245)	2.145 [*] (1.190)	0.526 ^{**} (0.191)
Log Likelihood	-916.15	-986.41	-983.75
Adjusted-R ²	0.19	0.19	0.19
AIC	1844.30	1984.81	1983.49
BIC	1873.98	2014.94	2023.66
Observations	1039	1120	1120
Number of farms	116	125	125

Significance levels: ^{***} robust p-value <0.001, ^{**} robust p-value <0.01, ^{*} robust p-value<0.05, ⁺ robust p-value<0.1. Robust standard errors in parentheses.

Source: own elaboration.

The Hausman-McFadden test reveals the IIA assumption is violated and there are preference heterogeneities across respondents, suggesting the need to rely on ML (Equation (3.4)) or LC (Equation (3.5)) models to characterise preferences. To disentangle preference heterogeneities, we first apply a ML model with attributes and status-quo coefficients defined as random parameters, except for the individual per-hectare payment coefficient. Second, we characterise groups of respondents with similar patterns of preferences using a LC model.

The first ML specification without individual specific variables (ML1) shows the density of hedgerows and the level of the individual per-hectare payment significantly affects respondents' choice with the expected signs (negative effect for the level of hedgerows requirements and positive effect of the level of payment) (Table 3.4). Preferences for the requirement of soil cover are significantly positive, which can be explained by the already high proportion of farmers fulfilling the highest level. Most of our farmers being located in a Nitrates Vulnerable Zone, they must comply with existing regulation which already involves cover cropping during specific periods of the year. The positive parameter might reveal farmers' willingness to be compensated for the effort they already conduct. Farmers exhibit positive preferences for the bonus options, but only the sponsorship bonus by itself is significant. The collective environmental result bonus can be perceived as riskier, as it does not only depend on farmers' individual efforts but also the cumulated efforts of others, as well as other external factors affecting water quality. This result may also reflect that some respondents do not believe the environmental target can be achieved in their area or within the contract length (5 years). The *status quo* was chosen in 13% of the choice situations (excluding protesters), and results suggest farmers tend to prefer choosing a contract rather than the opt-out option. The significance of the standard deviation coefficients shows strong preference heterogeneities for both management attributes, the *status quo* and the bonus option offering both the possibility of a sponsorship bonus and a collective environmental result bonus. The standard deviation of the sponsorship bonus preference parameter being not significant, we define the coefficient as non-random in the second specification.

Table 3.4. Mixed Logit estimations (normal distribution of random parameters).

	ML1	ML2
<i>PAYMENT</i>	0.006 ^{***} (0.001)	0.006 ^{***} (0.001)
<i>COVER</i>	0.036 [*] (0.017)	0.022 (0.022)
<i>COVER*ENVORGA</i>		0.094 ^{**} (0.039)
<i>HEDGEROWS</i>	-0.018 ^{**} (0.006)	-0.001 (0.010)
<i>HEDGEROWS*ENVORGA</i>	-	0.024 [*] (0.014)
<i>HEDGEROWS*ORGANIC</i>	-	0.030 ^{***} (0.008)
<i>HEDGEROWS*SHORT-TERM</i>	-	-0.041 ^{***} (0.011)
<i>HEDGEROWS*UAA</i> ¹	-	-0.002 ^{***} (0.001)
<i>BONUS</i> _{sponsorship}	0.278 ⁺ (0.185)	0.314 [*] (0.189)
<i>BONUS</i> _{sponsorship/collective result}	0.142 (0.244)	-1.306 ^{***} (0.400)
<i>BONUS</i> _{sponsorship/collective result} <i>*COLPAY</i>	-	0.564 ^{***} (0.155)
<i>BONUS</i> _{sponsorship/collective result} <i>*SHAREPGRASS</i>	-	1.349 ^{**} (0.499)
<i>ASC</i> _{sq}	-2.023 ^{***} (0.448)	-0.946 ^{**} (0.394)
<i>ASC</i> _{sq} <i>*ENVORGA</i>	-	-6.610 ^{***} (0.869)
<i>ASC</i> _{sq} <i>*HHDIVREVENU</i>	-	-4.613 ^{***} (1.305)
<i>SD.COVER</i>	-0.100 ^{**} (0.023)	0.111 ^{***} (0.028)
<i>SD.HEDGEROWS</i>	-0.061 ^{***} (0.009)	0.046 ^{***} (0.006)
<i>SD.BONUS</i> _{sponsorship}	-0.326 (0.325)	-
<i>SD.BONUS</i> _{sponsorship/collective result}	-1.375 ^{***} (0.266)	1.268 ^{***} (0.223)
<i>SD.ASC</i> _{sq}	3.317 ^{***} (0.401)	-3.116 ^{***} (0.372)
Log Likelihood	-725.21	-686.00
Pseudo-R ²	0.35	0.38
AIC	1472.42	1409.99
BIC	1526.82	1503.97
Observations	1039	1039
Number of farms	116	116

¹ Utilised agricultural area in 10ha. Significance levels: ^{***} robust p-value <0.001, ^{**} robust p-value <0.01, ^{*} robust p-value<0.05, ⁺ robust p-value<0.1. Robust standard errors in parentheses. Source: own elaboration.

In a second ML specification (ML2), we add interaction terms with individual specific variables collected in the survey. Out of the set of covariates tested, we kept those significantly explaining the heterogeneity of farmers' choices while not deteriorating the model's goodness of fit. As expected, farmers who are members of an environmental organisation (*ENVORGA*=1) and therefore particularly aware of environmental issues, exhibit lower preferences for the status-quo option and higher preferences for higher levels of management requirements attributes. Organic farmers (*ORGANIC*=1) have higher preferences for more ambitious levels of

hedgerows density requirements. We can assume organic farms value the multiple ecosystem services delivered by hedgerows (habitats for natural predators of pests, reducing exposure to pesticide spray drift from neighbouring farms...). On the other hand, respondents who plan to stop farming activities in 5 years or less (*SHORT-TERM*=1) have strong negative preferences for hedgerows requirements, which require long-term engagement for maintaining them. Large farms also tend to prefer lower levels of hedgerows requirements, for which compliance might be particularly costly. Regarding the bonus option, the higher the farmer's score (*COLPAY*={0,1,2,3,4}) in terms of the impact of a common payment on the willingness to adopt a contract, the higher his or her preferences for the combined sponsorship and collective result bonuses. It suggests that some farmers have "pro-collective" behaviour. Preferences for the combined bonuses also increase with the share of permanent grasslands in the cropping system (*SHAREPGRASS*). Finally, respondents for which farming contributes to less than 70% of the household gross revenue (*HHDIVREVENU*=1) are less likely to choose the status quo option. This is consistent with the findings by Defrancesco et al. (2008) that the high dependency of the households on agricultural income is a barrier to the adoption of AES.

Farmers' marginal WTA for the attributes are reported in Table 3.5. *Ceteris paribus*, a farmer accepts a contract with on average 43€ less of individual payment per hectare if there is a sponsorship bonus of 450€/peer. For a farm of 100ha (average farm size of the sample), it represents a decrease of 4,300€ in individual payment per year. A farmer would need to convince at least 10 new farmers each year to receive the same amount of sponsorship bonuses. This result confirms the result by Kuhfuss et al. (2016) that introducing a bonus option can improve the cost-effectiveness of a PES.

Table 3.5. Marginal willingness to accept the payment for environmental services contract design characteristics, estimated with the delta method (€/ha/year).

	ML1
<i>COVER</i>	-5.578* (2.782)
<i>HEDGEROWS</i>	2.885** (0.930)
<i>BONUS</i> <i>sponsorship</i>	-43.485+ (29.174)
<i>BONUS</i> <i>sponsorship/collective result</i>	-22.280 (37.854)
<i>ASC</i> _{sq}	316.320*** (85.869)

Robust standard errors in parentheses. Significance levels: *** robust p-value <0.001, ** robust p-value <0.01, * robust p-value<0.05, + robust p-value<0.1.

Source: own elaboration.

We further characterise preference heterogeneities by estimating a LC model. The best model fit was obtained for 3 and 4 classes, as the Bayesian information criterion (BIC) increases starting from 5 classes (Table 3.6). We decided to keep 3 classes to limit the number of variables in the model and add individual specific variables to explain class membership.

Table 3.6. Selection of Latent Class model.

Number of classes	2	3	4	5	6
Log Likelihood	-796.07	-715.8	-692.42	-673.93	-662.43
AIC	1618.13	1471.6	1438.84	1415.85	1406.87
BIC	1682.43	1570.52	1572.38	1584.01	1609.65
Pseudo-R ²	0.2912	0.3554	0.3697	0.3798	0.3837
Average probability to belong to the attributed class	0.9777	0.968	0.9501	0.9445	0.9254

Source: own elaboration.

The first class (57% of respondents) describes farmers with positive preferences for both types of bonus options, and with the highest preferences for the individual per-hectare payment (Table 3.7). Relative to the other classes, the level of financial incentive seems to drive their choice more than technical constraints. Farmers who are members of an environmental organisation, and therefore have experience in working collectively on environmental issues, are more likely to belong to this “pro-incentive” class. The second class of farmers (29% of respondents) exhibits preferences for low management requirements and is not affected by the bonus option. Conventional farmers and farmers stopping their activity within 5 years are more likely to be in this “management change averse” class. The third class (14% of respondents) depicts farms preferring PES contracts with high management requirements and no bonus option. Organic farmers and farmers for which the household income is highly dependent on farming are more likely to be in this “pro-environment individualists” class. The preference parameter for the individual per-hectare payment is not significant, suggesting that the individuals’ choice is more driven by the contract design in itself than by the incentive. While the third class describes a small share of the sample, it reveals the low acceptance of bonus incentives from a part of the farming population in the surveyed area, either because they prefer current action-based PES, or because they are reluctant to collective approaches.

Table 3.7. Latent Class estimation.

	Class 1	Class 2	Class 3
<i>PAYMENT</i>	0.008** (0.003)	0.002⁺ (0.002)	0.001 (0.001)
<i>COVER</i>	0.041* (0.021)	-0.055** (0.020)	0.107*** (0.031)
<i>HEDGEROWS</i>	0.005 (0.004)	-0.041* (0.022)	0.020** (0.007)
<i>BONUS</i> <i>sponsorship</i>	0.989*** (0.206)	0.103 (0.428)	-0.708* (0.395)
<i>BONUS</i> <i>sponsorship/collective result</i>	1.216* (0.523)	-0.392 (0.340)	-1.027** (0.400)
<i>ASC</i> _{sq}	-2.601* (1.519)	0.335 (0.491)	-1.952*** (0.464)
Log likelihood	-700.61		
Pseudo-R ²	0.3617		
AIC	1457.21		
BIC	1595.7		
Observations	1039		
Number of farms	116		
Probability of class	0.6078	0.1607	0.2314
Share of respondents (%)	56.90	29.31	13.79
Class membership function			
Intercept		-0.129 (0.655)	-1.726** (0.609)
<i>SHORT-TERM</i>	-	1.013⁺ (0.774)	-0.443 (0.854)
<i>ORGANIC</i>	-	-0.985⁺ (0.643)	1.476* (0.726)
<i>ENVORGA</i>	-	-15.615*** (1.392)	-1.352⁺ (0.828)
<i>HHDIVREVENU</i>	-	-0.710 (0.809)	-12.054*** (1.578)

Significance levels: *** robust p-value <0.001, ** robust p-value <0.01, * robust p-value <0.05, + robust p-value <0.1. Robust standard errors in parentheses.

Source: own elaboration.

3.5. Concluding remarks

The effectiveness of payment schemes for farmers' environmental services aiming at the delivery of environmental public goods with provision thresholds (biodiversity, water quality) depends on reaching enough farmland enrolment and aggregated environmental effort at the landscape scale. The objective of the present study was to elicit farmers' preferences for a payment mechanism made of a bonus incentivising farmers to adopt a collaborative behavior with other farms from the same area, on top of an individual action-based payment. In comparison to collective requirements conditioning the full payment, the conditional bonus option reduces the risk of receiving no compensation for one's environmental services if the aggregated effort and surfaces are insufficient at the landscape scale. Using a CE approach, we measured preferences for a sponsorship bonus of 450€/sponsored farmer rewarding individual

farmers for increasing participation, and a combined bonus option comprising the sponsorship bonus and a collective result bonus of 50€ per hectare delivered to all participants if an environmental target is met at the landscape level.

Findings suggest that on average, respondents prefer contracts with a bonus for sponsoring a peer to no bonus, but are less favorable to a combined sponsorship/collective result bonus. Designing bonuses distributed according to an individual effort for attracting more farmers could be a promising way to increase participation and PES cost-effectiveness, while collective bonuses distributed to all might be counterproductive. We characterised respondents' heterogeneity with a latent class model and identified three groups of farmers with a different attitude towards the bonus options: (i) "pro-environment individualists" with negative preferences for both, (ii) farmers who seem indifferent to both, and (iii) "pro-incentive" farmers with positive preferences for both.

A limit to the generalisation of our findings is that due to the sampling procedure, our data are biased. Asking and controlling for individual status-quo levels allowed us to control part of the bias regarding the already high levels of management requirements implemented by respondents. In addition, there is an over-representation of organic farms (39% of the respondents while the actual share is closer to 10%). Since organic farms are more likely to have a "pro-environment individualist" preference pattern, our results likely overestimate the negative attitude towards the bonus option, in particular towards the combined sponsorship/collective environmental result bonuses.

To ensure sufficient adoption, the introduction of PES with conditional bonuses may require paying farmers beyond opportunity costs. The involvement of private and local stakeholders in financing PES represents an opportunity to capture a higher willingness to pay for water quality. In particular, bonus-mechanisms rewarding a landscape result or high participation could be of particular interest to stakeholders benefiting directly from the improvement of rivers' ecological quality (water bottle companies, water catchment bodies...). Another issue at stake in capturing more willingness to pay for PES is to consider the other public goods provided in synergy with the implementation of hedgerows and the reduction of bare soil duration, such as carbon storage and the protection of agrobiodiversity. On the one hand, the emergence of carbon and biodiversity offsets together with watershed payments represents an opportunity for farmers to find contributors more easily, and valorise the multiple environmental services they provide. Stakeholders from north-western France seem particularly interested in developing local carbon

markets based on the valorisation of a bunch of public goods (Dupraz et al., 2020). On the other hand, the multiplication of those initiatives could lead to counterproductive effects. Different payment levels for the implementation of the same practices depending if a contributor values more water quality, carbon storage or biodiversity raise the issue of fairness. It might provide an additional incentive for farmers to work together in securing a collective supply of environmental services at the landscape level and increase their bargaining power. In areas where experience in collective approaches is low, building institutions facilitating collective action would support this process (Kerr et al., 2014).

Further research is needed to assess if conditional bonuses are successful in improving public good provision in practice. An AECM to protect the European Hamster in France recently introduced an individual bonus payment when a burrow is detected on a plot (Eichhorn et al., 2022). This case study might provide useful empirical evidence to build on in the future.

Chapter 4. Taking the diet of cows into consideration in designing a payment to reduce enteric methane emissions on dairy farms

This chapter focuses on the design of result-based dedicated payments for environmental services (PES). The conditionality rules of result-based PES define a payment based on the achievement of an environmental outcome, rather than the implementation of prescribed practices. In theory, they exhibit the payment mechanisms the most targeted towards public good provisioning. The design of result-based PES aims at cost-effectiveness, as the payment conditionality ensures that there is no payment without environmental output. It also favours the efficiency of farmers, who are free to choose the less costly practices adapted to their situation to meet the contractual requirements. Only three agri-environment-climate measures (AECM) with result-based features were proposed in France during the 2014-2020 common agricultural policy (CAP) programming period, with payments conditioned to the presence of a minimum number of specific flower species on grasslands. Private initiatives also emerged for the reduction of GHG emissions or carbon storage in agricultural soils, measured in tonnes of carbon dioxide equivalent. For instance, the result-based scheme Eco-Methane proposes a payment proportional to the reduction of enteric methane emissions on French dairy farms. Implemented since 2011, participation after 10 years remains marginal (around 2.3% of French dairy farms) (Bleu-Blanc-Coeur, 2022b). It suggests that despite their intrinsic advantages, barriers remain to the implementation of successful result-based PES.

Observations from the Eco-Methane programme were the starting point for the empirical analysis developed in this chapter. We discuss two design elements of PES targeting the reduction of enteric methane emissions on dairy farms, which are crucial for their effectiveness: (i) the choice of emissions indicator capturing the effect of farmers' practices and (ii) the payment amount relative to the extra milk production costs incurred. Using representative farm-level economic data from the farm accountancy data network (FADN), we compare enteric methane emissions per liter of milk calculated with an Intergovernmental Panel on Climate Change Tier 2 method, to baseline emissions from a Tier 3 method accounting for diet effects. We also quantify the extra milk production costs of integrating more grass in the fodder systems by estimating variable cost functions for different dairy systems in France.

This chapter was co-authored with Sabine Duvaleix (Institut Agro, SMART) and Pierre Dupraz (INRAE, SMART), and involved the following individual contributions: Fanny Le Gloux: conceptualisation, investigation, methodology, formal analysis, validation, original draft; Sabine Duvaleix: conceptualisation, methodology, supervision, validation, review and editing; Pierre Dupraz: conceptualisation, supervision, validation. The study was presented at the 14th Annual Social Science Conference INRAE, SFER, CIRAD (7th-8th April 2021, online), and won a Best Poster Award at the 95th Annual Conference of the Agricultural Economics Society (29th-30th March 2021, online). The analyses also contributed to deliverables D2.6 (Eichhorn et al., 2022) and D3.1 (Dupraz et al., 2022) of the CONSOLE project (<https://console-project.eu/>). A preliminary version of the article was published as a Working Paper (Le Gloux et al., 2021). This present version has been submitted to the Journal of Dairy Science in September 2022 and is under revision.

4.1. Introduction

The agricultural sector is a major source of greenhouse gases (GHG), accounting for 10% of EU-KPs (European Union, United Kingdom and Iceland) in 2018 (Citepa, 2020a; EEA, 2020b). 81% of agricultural methane emissions result from enteric fermentation, and 39% of those 81% are produced by dairy cows (EEA, 2020b). Methane is the second contributor to radiative forcing. Currently, the global warming potential of methane is set at 28 times higher than the global warming potential of carbon dioxide over 100 years and 84 over 20 years (Myhre et al., 2013). As methane is a short-lived climate pollutant continuously destroyed in the atmosphere, its effect on climate change depends mostly on short-term emission rates. In theory, decreasing the methane emissions rate below its natural destruction rate would have a cooling effect (Cain et al., 2019). Therefore, a significant reduction in methane emissions, in particular from agricultural activities, would rapidly mitigate climate change and is a powerful lever to meet the European Union's 2050 climate targets (Dupraz, 2021).

Enteric fermentation is identified as the first source of GHG emissions from dairy farms in both developed and developing countries (Jayasundara et al., 2019; Wilkes et al., 2020). The quantity of methane produced during the digestive process of ruminants depends highly on the characteristics of the animal itself, such as the breed, body weight and age (Gavrilova et al., 2019). However, enteric methane emissions are also directly related to farming practices, in particular the amount of feed intake and composition, and the proportion of carbohydrates that feed ration contains (Martin et al., 2010). In particular, for a given productivity level, enteric methane emissions decline as dairy cow feed is enriched with alpha-linolenic acid ALA (polyunsaturated fatty acid of the omega-3 family), for which the main natural sources are linseed and grass fodders (Chilliard et al., 2009; Dong et al., 1997; Grainger and Beauchemin, 2011; Martin et al., 2011, 2010, 2008, 2006). Moreover, as productivity per cow increases, methane emissions per kilogram of milk decrease (Martin et al., 2006). Animal productivity can also be improved through nutrition, as well as through herd's management and genetics (Boadi et al., 2004). To accurately monitor the evolution of enteric methane emissions on dairy farms, one must consider both dimensions (productivity and feeding). Authors show enteric methane emissions can differ significantly from one indicator to another and recommend considering both production intensity and feed usage for more accurate estimates (Hagemann et al., 2011; Sauvart et al., 2011).

Economic incentives are currently being developed in the agricultural sector to support the reduction of GHG emissions. Changing management practices, and in particular cows' diet, to decrease enteric methane emissions may be costly for many farmers, and can be supported financially through payments for environmental services (PES). Developing PES schemes for the reduction of enteric methane emissions raises the question of the choice of a practical emission indicator sensitive to both diet and productivity effects, easily applicable and measurable on the farms. While numerous other motivations may encourage farmers to join a PES program, such as improving milk quality, environmental quality, zootechnical performance and the image of agriculture, economic interests are likely to be crucial factors. An efficient payment level of a PES scheme targeting GHG emissions is equal to the socially optimal carbon price. In the EU, carbon tax levels differ largely among countries. In 2021, it was set at 120€/teqCO₂ in Sweden and 45€/teqCO₂ in France, while the EU ETS (European Trading System) market price was 44€/teqCO₂ (The World Bank, 2021).

In this paper, we aim to provide insights into the design of PES schemes targeting the reduction of enteric methane emissions in dairy farms by examining two aspects of a payment mechanism for which failing to consider the feeding dimension could undermine its effectiveness in cutting enteric methane emissions: the choice of emissions indicator defining the environmental service, and the level of payment. By comparing an indicator constructed using a methodology applied in a real-life case study from France to the Tier 2 indicator currently used in the French annual GHG emissions inventory which considers productivity only, we examine how the diet of dairy cows influences the enteric methane emissions attributed to farms. Changing the diet of cows to improve the milk fatty acid profile can generate additional production costs that are not yet evaluated. The second contribution is to quantify the additional cost of a change in the diet of cows at the farm level to evaluate the economic incentives needed for improving dairy systems towards more environment-friendly practices. We estimate the variable cost function of dairy farms at the scale of France and for different fodder systems.

4.2. Background on enteric methane emission indicators

Many indicators of enteric methane emissions have been developed and adapted to specific constraints, often related to the scale of their application and the data available for estimating emissions (Ellis et al., 2007; Kebreab et al., 2006; Negussie et al., 2017). For result-based PES,

emissions should regularly and easily be monitored on the farms. The emission indicator chosen must therefore be easily measurable by the farmers and/or the paying agent using a simple methodology, representative of the environmental target and reliable (based on strong and reliable scientific evidence) (Allen et al., 2014). In addition, it must be sensitive to the different dimensions on which farmers can act to decrease emissions, in particular cows' diet and productivity.

The Intergovernmental Panel on Climate Change (IPCC) defines 3 families of methods, to be applied for national inventories according to data availability. Tier 1 methods attribute default yearly enteric methane emissions factor per dairy cow. Tier 1 methods provide aggregate estimates, and are not adequate for monitoring changes over time and considering the variability of dairy farming practices. Tier 2 methods improve the accuracy of emission factors by including feed intake estimates of a representative diet and dairy cow (Gavrilova et al., 2019). Finally, Tier 3 methods require a precise characterization of cows' diets to account for digestibility. Both Tier 2 and Tier 3 approaches for France are presented in Eugène et al. (2019).

Several recent studies applied those indicators. Stetter and Sauer (2022) applied a Tier 1 enteric methane emission indicator at the micro scale but as part of an overall assessment of the relative GHG emissions and economic performance of farms. Life cycle assessment analyzes calculating the carbon footprint of dairy products tend to apply Tier 2 methods (Jayasundara et al., 2019; Wilkes et al., 2020), sometimes also including diet composition data (Gollnow et al., 2014; Hagemann et al., 2011). Bioeconomic models estimating emissions abatement costs in the agricultural sector use Tier 3 indicators of enteric methane emissions precise enough to capture both productivity and diet effects (Lengers et al., 2013; Mosnier et al., 2019). Most Tier 3 and "individualized" Tier 2 approaches mentioned above require a large amount of detailed individual farm-level data on cows' feed composition, making it too costly to be applied as monitoring indicators on a large number of farms. However, some of the Tier 3 methods can use information from milk analyzes and thus, be more easily integrated into farm routines.

4.3. A Tier 3 indicator applied in the Eco-Methane result-based scheme

Numerous studies have been carried out to understand the connection between dairy cows' enteric methane emissions, fat intake and milk composition (Chilliard et al., 2009; Dong et al., 1997; Grainger and Beauchemin, 2011; Martin et al., 2011, 2010, 2008, 2006). In particular,

experimental research shows that enteric methane emissions in gCH₄/L (*Methane*) can be calculated from milk productivity in kg/cow/year (*Productivity*) and the ratio of the sum of fatty acids with 16 carbon atoms or less ($FA \leq C16$) to the total amount of fatty acids (*TotalFA*) in the milk they produce (Equation (4.1)). This ratio has a strong biological causal relationship with methanogenesis in the rumen and is significantly reduced by more sources of omega-3 in cows' diet.

$$Methane = 11.368 * Productivity^{-0.4274} * \frac{FA \leq 16}{TotalFA} \quad (4.1)$$

This formula was coinvented by teams from the animal feed manufacturing company Valorex (P. Weill and G. Chesneau) and the French National Institute for Agricultural Research (INRA) (Y. Chilliard, M. Doreau and C. Martin), and received a patent under the title “Method for evaluating the quantity of methane produced by a dairy ruminant and method for decreasing and controlling such quantity” (WO2009156453A1) (Weill et al., 2009). The necessary data to implement it are relatively easy to collect on farm. One needs milk productivity and an analysis of the fatty acid composition of milk, obtained with infrared spectroscopy. Milk infrared spectroscopy is relatively simple to integrate into the milk analyzes routines of dairy farms and involves low costs. Since dairy farms already undertake milk analyzes regularly, it makes it a relatively cheap indicator to monitor emissions. In addition, the equation calculates enteric methane emissions per unit of product by taking into account both milk productivity and feed quality, hence captures both dimensions on which farmers can dedicate effort to reduce emissions.

The indicator described above is used since 2011 to evaluate the reduction of enteric methane emissions of dairy farms participating in the PES scheme Eco-Methane in France, implemented and coordinated by the Bleu-Blanc-Coeur association. Eco-Methane meets the reference PES definition by Wunder (2015). In the scheme, private stakeholders (service users) give financial support to volunteer dairy farmers (service providers) for actions that contribute to climate change mitigation (environmental services). The payment is conditional and proportional to the reduction of CO₂eq, making the scheme a result-based PES. The reduction is calculated relative to baseline monthly emission levels attributed to the farms that are representative of its type of fodder system. Through the definition of different baseline scenarios, the PES design partially considers the variability in the potentiality of environmental services provision according to the production basin and the fodder system. Hence, rather than rewarding farms that produce the

least emissions per unit of product (which would tend to favor the most productive farms), Eco-Methane supports all emission reduction efforts.

The Eco-Methane scheme uses eleven scenarios of baseline emission levels representative of 11 fodder systems of French specialized dairy farms. These fodder systems were characterized by the French Dairy Interbranch Organization (CNIEL) in collaboration with the French Livestock Institute (IDELE) in 2009, based on large production basins (plain and mountainous areas), and the proportion of corn in fodder crop rotation systems (CNIEL, 2015). The baseline emissions for each scenario are determined by Bleu-Blanc-Coeur using equation (4.1).

Eco-Methane brings together more than 600 farmers whose emissions reduction was estimated at 11% on average in 2017 (Bleu-Blanc-Coeur, 2022b). Bleu-Blanc-Coeur pays farmers according to their reduction of methane emissions in CO₂eq with a financial envelope made of donations from private actors (15€/tCO₂eq on average in 2017). The main strengths of the scheme lie in the strong scientific foundations of the method for quantifying emissions and the easy participation procedure for dairy farmers. Each contract signatory commits to provide a monthly milk analysis to the association and to include feed with a high content of sources of omega-3 in dairy cow rations (alfalfa, extruded linseed, grass). These data are used to estimate enteric methane emissions using equation (4.1). Eco-Methane is recognized by the United Nations as a GHG emission reduction project eligible for issuing carbon credits (UNFCCC, 2016).

4.4. Materials and methods

4.4.1. Data

Observations of a balanced panel of 735 French dairy farms from France's farm accountancy data network (FADN) for the years 2016 to 2018 were selected for the analysis. This European database is freely accessible online and representative of socioeconomic and accountancy information of medium and large dairy farms contributing to more than 90% of the gross production and utilized agricultural area. Due to this characteristic, it is a particularly relevant dataset to investigate emission abatement costs at the national level. As the compositions of the feed ration and milk are not surveyed, information on the diet of dairy cows is limited and in

particular, the fatty acid profile is unknown. Instead, data on the fodder crop rotation systems are used to assess a change in crop rotation and approximate a change in feed composition. Descriptive statistics of the sample are presented (Table 4.1).

Table 4.1. Description of the sample (N=2,205)

Variable	1 st quartile	Median	Mean	3 rd quartile
Utilized Agricultural Area (ha) ¹	50.0	80.0	87.4	110.0
Fodder area (ha) ¹	40.0	60.0	67.4	80.0
Corn silage area (ha) ¹	1.0	10.0	14.1	20.0
Pasture area (ha) ¹	26.0	40.0	50.3	61.0
Productivity (L/cow/year)	5,593.4	6,676.4	6,707.9	7,851.1
Number of dairy cows ¹	35	55	58	70
Agricultural Work Unit	1.0	2.0	1.8	2.1
Purchase of cattle feed concentrates (€)	14,326.0	24,996.5	32,853.2	43,645.0

¹ Information on surfaces and the number of dairy cows available in the database are ranges of values. We constructed the variables used in the analysis by taking the lower value of the range for each observation.

Source: French 2016-2018 FADN data.

4.4.2. Attribution of enteric methane emissions

We use the Tier 2 method used in the French annual inventory of GHG emissions to define an indicator of enteric methane emissions sensitive to productivity effects. Dairy cows' emission factors are calculated from equation (4.2) (Citepa, 2020b).

$$EF = 0.0105 * \frac{\text{Milk production}}{N_{\text{cows}}} + 48.971 \quad (4.2)$$

The emission factor EF (kgCH₄/cow/year) can be easily calculated for each farm of the FADN from the milk production (kg/year) of the herd (*Milk production*) and the number of dairy cows (N_{cows}). We then derive an emission indicator (*TIER2*) per liter of milk, capturing variability according to milk productivity (L/cow/year):

$$TIER2 = \frac{EF}{\text{Productivity}} \quad (4.3)$$

Due to the absence of data on dairy cows' diets, a Tier 3 method cannot be applied to evaluate individual emissions of FADN farms and capture both productivity and diet effects. In particular, data are too limited to estimate individual enteric methane emissions of French farms using equation (4.1). They are, however, sufficient to identify their Eco-Methane scenario and therefore the baseline emissions corresponding to their fodder system. Baseline emissions from the 11 scenarios are available per month and were obtained from Bleu-Blanc-Coeur. We calculate the annual average to define the Eco-Methane baseline emissions indicator (*Eco-Methane baseline*) (Table 4.2).

Table 4.2. Characteristics of the eleven baseline scenarios used in the Eco-Methane scheme

Scenario	Corn in the fodder area	Production basin	Eco-Methane baseline (gCH ₄ /L)
1	More than 30%	Plains outside the western region	15.75
2		Plains of the western region	15.92
3	Between 10 and 30%	Plains outside the western region	15.83
4		Plains of the western region	16.43
5	Less than 10%	Plains outside the western region	16.56
6		Plains of the western region	17.38
7	More than 10%	Mountains	15.96
8	Less than 10%	Mountains of the Massif Central	17.13
9		Mountains of the Northern Alps	17.83
10		Mountains of Franche-Comté	16.22
11		Other mountains	17.20

Source: Bleu-Blanc-Coeur data.

An individual baseline scenario was assigned to each farm of the sample based on two criteria: the location and the share of corn silage in the fodder area of the farm. In the FADN database, the farm location variable corresponds to the 21 old French administrative regions (the administrative divisions were changed in 2015), while the Eco-Methane scenarios are defined according to large production basins built from a lower administrative level (departments). It was therefore necessary to allocate a production basin to each administrative region. For the

regions with departments belonging to different production basins, we allocated the basin of the departments producing the highest volumes of milk to the entire region. This attribution was made using the 2018 annual dairy survey (Agreste, 2019) and is detailed in Appendix A5.

4.4.3. Estimation of the extra-cost of milk production with more grass in the fodder system

The optimal payment level of a PES scheme lies between society's willingness to pay for climate change mitigation and farmers' willingness to accept for reducing emissions. The optimal price of climate change mitigation corresponds to the optimal tax rate of CO₂ emission. In France, the closest financial tool to a carbon tax is the Climate and Energy Contribution proportional to the carbon dioxide content of energy products (fossil fuels) (Rogissart et al., 2018). The contribution level was 30€/tCO₂eq in 2017 and increased to 40€/tCO₂eq in 2018 and 2019. Farmers participating in Eco-Methane received an average of 15€/tCO₂eq in 2017, suggesting that the payment of the scheme is suboptimal and provides little incentive to participate (Bleu-Blanc-Coeur, 2022b). Evaluating farmers' willingness to accept is necessary to define a more efficient price and trigger a large scale adoption of practices decreasing enteric emissions.

Since the composition of the feed ration and milk of cows are not available in the FADN, the effect of an improvement of the fatty acid profile on milk production costs cannot be analyzed directly. Instead, an evolution of the fodder crop rotation is assumed. As grass is a high source of omega-3 fatty acids strongly encouraged in Eco-Methane, we assume that a commitment to the program would lead to an increase in grassland surfaces on farms. This hypothesis is quite strong and implies that the estimation of extra costs does not consider either the strategy of supplementing the ration with other feeds with high omega-3 content such as extruded linseed or the optimization of grazing increasing grass yield and quality without necessarily increasing grassland surfaces.

Based on dual production theory (McFadden, 1978), we estimate a variable cost function describing expenditures in variable production factors x with exogenous input prices w that minimize variable costs given the production level y targeted by the farmer and available quasi-fixed inputs z such as land, labor and equipment that are assumed to be predetermined in the short term. The variable cost function is defined as follows:

$$VC(w, y, z) = \min_x wx \text{ subject to } y \leq f(x, z) \quad (4.4)$$

The variable cost function meets several theoretical properties. It must be concave, nondecreasing and homogeneous of degree 1 in input prices, decreasing with fixed factors of production, and convex according to output levels.

We estimate a system of equations comprising a homogeneous translog cost function (4.5) in which variable costs VC correspond to intermediate consumption and the variable input cost share functions (4.6) and (4.7), derived from Shephard's lemma.

$$\begin{aligned} \ln \frac{VC_{it}}{W_{1it}} = & \alpha_0 + \sum_{r=1}^2 \beta_r \ln Y_{rit} + \alpha_2 \ln \frac{W_{2it}}{W_{1it}} + \frac{1}{2} \alpha_{22} \left(\ln \frac{W_{2it}}{W_{1it}} \right)^2 + \sum_{h=1}^3 \delta_h \ln Z_{hit} + \\ & \frac{1}{2} \beta_{11} \ln Y_{1it}^2 + \frac{1}{2} \sum_{h=1}^3 \sum_{k=1}^3 \delta_{hk} \ln Z_{hit} \ln Z_{kit} + \sum_{h=1}^3 \nu_{2h} \ln \frac{W_{2it}}{W_{1it}} \ln Z_{hit} + \\ & \sum_{h=1}^3 \rho_{1h} \ln Y_{1it} \ln Z_{hit} + \zeta_{12} \ln Y_{1it} \ln \frac{W_{2it}}{W_{1it}} + e_{it} \end{aligned} \quad (4.5)$$

$$\frac{X_{1it} W_{1it}}{VC_{it}} = 1 - \alpha_2 - \alpha_{22} \ln \frac{W_{2it}}{W_{1it}} - \sum_{h=1}^3 \nu_{2h} \ln Z_{hit} - \zeta_{12} \ln Y_{1it} + u_{1it} \quad (4.6)$$

$$\frac{X_{2it} W_{2it}}{VC_{it}} = \alpha_2 + \alpha_{22} \ln \frac{W_{2it}}{W_{1it}} + \sum_{h=1}^3 \nu_{2h} \ln Z_{hit} + \zeta_{12} \ln Y_{1it} + u_{2it} \quad (4.7)$$

The translog functional form is commonly used in the literature on the cost structure and efficiency of dairy farms because of its flexibility and the possibility of imposing homogeneity of degree 1 (Alvarez and Arias, 2003; Moschini, 1988; Mosheim and Lovell, 2009; Nehring et al., 2009; Singbo and Larue, 2016; Sobczykński et al., 2015; Wimmer and Sauer, 2020). i and t are indices for individuals and years, respectively. We assume that dairy farms produce one output, the quantity Y_1 of the milk of cows produced per year (*Milk production*), the other products would be considered as a control variable. We consider two variable inputs, fuel X_1 and cattle feeding stuffs X_2 , for which the expenses represent a high share of intermediate consumption. The choice of including fuel is motivated by the possibility of calculating farm-level fuel prices and therefore capturing more heterogeneity. The price of fuel W_1 (*fuel price*) is calculated from the nonroad gas oil expenses and volumes. As individual cattle feeding stuff prices are not available in the data, W_2 (*feed price*) is measured by the index of purchase prices of the means of agricultural production (IPAMPA) for adult cattle feeding stuffs of year $t-1$, available for each French current administrative region. We also include three quasi-fixed inputs. Grassland surface Z_1 (*grassland*) includes permanent and temporary pastures, alfalfa for dehydration and other artificial fodders. We add two other quasi-fixed factors of production:

machinery and constructions fixed assets Z_2 (*capital*) and annual work units Z_3 (*labor*). The aggregated volume Y_2 of the other products of the farm (*other productions*) allows us to capture the heterogeneity linked to diversification. Y_2 is calculated as the total gross product of the year (crop products, livestock products and other products) net of animal purchases and milk production of the cows, deflated by the French agricultural producer price index (API) of year t . e_{it} , u_{1it} and u_{2it} are the error terms assumed to follow a normal distribution.

As grassland areas, milk production and input use can be simultaneous decisions, and $\ln Z_{1it}$ and $\ln Y_{1it}$ are likely to be correlated with the error terms. To correct for endogeneity, a three-stage least squares regression analysis with instrumental variables (3SLS-IV) is adopted. We include as instrumental variables the milk selling price P_1 (*milk price*), the utilized agricultural area (UAA) Q_1 (*utilized agricultural area*), the permanent pasture area Q_2 (*permanent pastures*), the number of dairy cows on farm Q_3 (*number of dairy cows*) and 20 regional dummies D_{ri} approximating the pedoclimatic conditions. These variables were chosen to capture important factors influencing the simultaneous decisions made by farmers regarding cattle feeding strategy and output level each year. By doing so, we assume that the UAA and surfaces of permanent pastures (installed for at least 5 years) are exogenous over the period of the analysis (3 years). The number of dairy cows is included as an instrumental variable based on the observation that Q_3 presents little intraindividual variability from one year to the next. Therefore, we consider the number of dairy cows to be a quasi-fixed decision in the short term and keep it in the model. The instrument M_{it} comprising all the exogenous and instrumental variables of the model is used to regress the endogenous variables in the three equations of the system and is presented in Appendix A6.

The system of equations (4.5) + (4.6) + (4.7) is estimated for all the farms of the sample and then for the three major production basins and groups of Eco-Methane scenarios defined in Table 4.2 to identify potential differences in extra costs according to the type of dairy system. Descriptive statistics of the model variables of the sample and subsamples are presented in Table 4.3.

Table 4.3. Mean values of the model variables

Variable	France N=2,205	Western plains N=645	Plains outside the western region N=965	Mountains N=585	Plains, >30% of corn N=767	Plains, ≤ 30% of corn N=853
Scenarios	1-11	2, 4, 6	1, 3, 5	7-11	1-2	3-6
Variable Costs (€/year)	128,073.5 (105,612.7)	139,405.3 (107,167.1)	136,399.4 (112,800.6)	96,533.0 (80,772.0)	170,654.1 (124,937.8)	112,079.6 (58,355.4)
Milk production (L/year)	398,594.1 (297,513.2)	446,128.0 (328,781.5)	402,355.2 (296,923.0)	306,703.0 (226,416.1)	526,707.0 (333,580.8)	348,741.1 (254,671.3)
Other productions (€/base 100/year)	498.6 (671.5)	581.3 (642.3)	554.6 (770.2)	274.4 (413.0)	750.2 (871.1)	425.9 (512.3)
Fuel price (€/L)	0.60 (0.10)	0.59 (0.10)	0.59 (0.11)	0.61 (0.10)	0.59 (0.10)	0.60 (0.10)
Feed price (base 100)	96.6 (2.4)	96.5 (2.4)	96.6 (2.4)	96.8 (2.3)	96.6 (2.4)	96.6 (2.4)
Grassland (ha)	51.1 (41.0)	42.1 (31.5)	52.7 (38.6)	65.5 (47.8)	34.2 (25.8)	56.3 (39.2)
Capital (1000€)	171.0 (155.9)	160.5 (146.8)	179.4 (163.7)	179.5 (160.8)	189.1 (161.8)	151.6 (145.9)
Labor (AWU)	1.8 (1.0)	1.9 (1.0)	1.9 (1.0)	1.7 (1.0)	2.0 (1.1)	1.7 (1.0)
Milk price (€/1000L)	362.3 (74.1)	343.5 (41.1)	367.0 (61.2)	390.5 (101.3)	333.1 (27.3)	369.4 (66.7)
UAA (ha)	87.4 (58.1)	84.3 (55.3)	92.6 (60.0)	86.3 (57.8)	93.3 (60.6)	83.2 (55.8)
Permanent pastures (ha)	30.7 (41.9)	14.6 (31.9)	40.0 (36.9)	48.0 (49.4)	13.9 (23.0)	34.2 (41.3)
Number of dairy cows	58.0 (36.7)	63.2 (42.5)	57.9 (34.0)	48.4 (30.9)	70.5 (40.7)	53.5 (32.7)

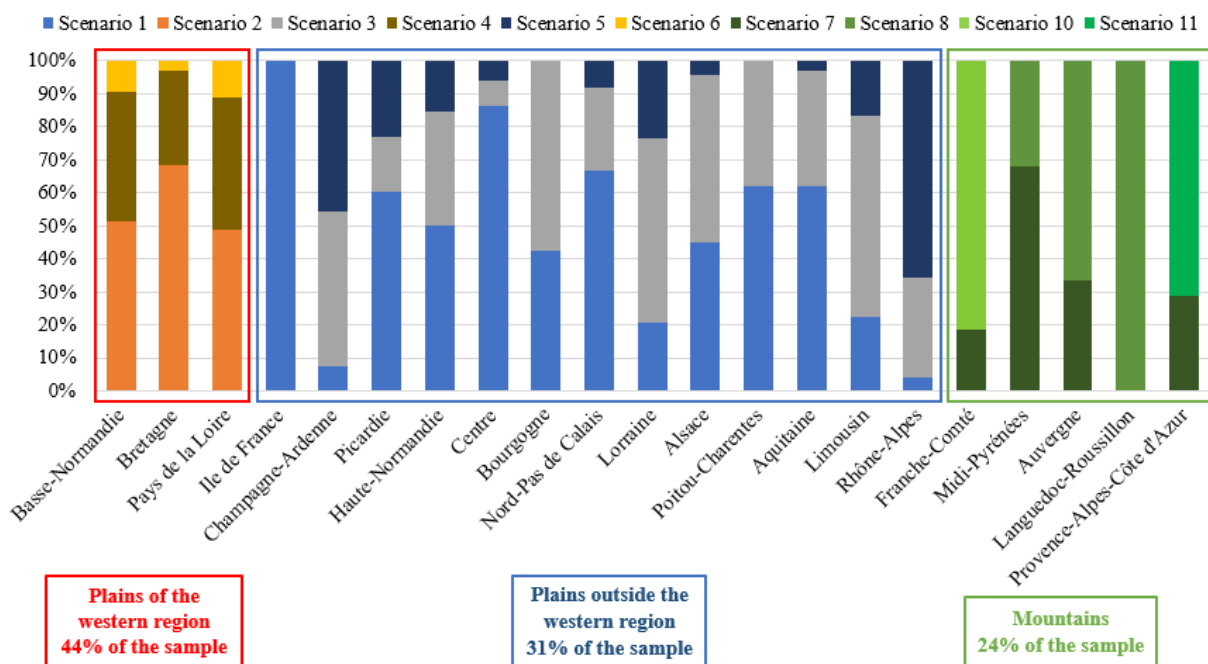
Weighted average. Standard deviation in parentheses.

Source: The authors, based on 2016-2018 French FADN data.

4.5. Results and discussion

4.5.1. Allocation of Eco-Methane scenarios and distinction of three milk production basins

Following the allocation of the Eco-Methane baseline scenarios to the farms of the sample, their proportion within each region can be observed (Figure 4.1). Farms in the regions of the western plains basin (Brittany, Pays de la Loire and Basse-Normandie) represent 44% of the sample and are characterized by a strong dominance of corn silage and few grasslands in forage crop rotation systems. For example, 68% of farms in Brittany would be assigned scenario 2 with more than 30% of corn in the forage crop rotation and 28% scenario 4 with 10 to 30%. The administrative regions of the plain production basin outside the western region (31% of the sample) and of the mountainous areas (24% of the sample) are quite different. Some plain regions, such as Rhône-Alpes, contain a high proportion of grazing systems dominated by grasslands (less than 10% of corn silage in the fodder crop rotation), while others, such as the Centre, have more intensive systems dominated by corn silage. All the observations from Languedoc-Roussillon correspond to grazing systems, while the observations from Midi-Pyrénées have a relatively small proportion (32%). Due to the missing information on departments in the FADN dataset and our scenario allocation procedure, some farms have been allocated to a plain system scenario, while, in reality, they are located in a mountainous department and vice versa. This allocation might partly explain the large share of farms with grazing systems in Rhône-Alpes. Nevertheless, those farms produce relatively low volumes of milk in comparison with plain farms from the same region.



Source: The authors, based on 2016-2018 French FADN and Bleu-Blanc-Coeur data.

Figure 4.1. Distribution of Eco-Methane baseline scenarios among French regions.

4.5.2. Enteric emissions: relation to productivity and fodder system

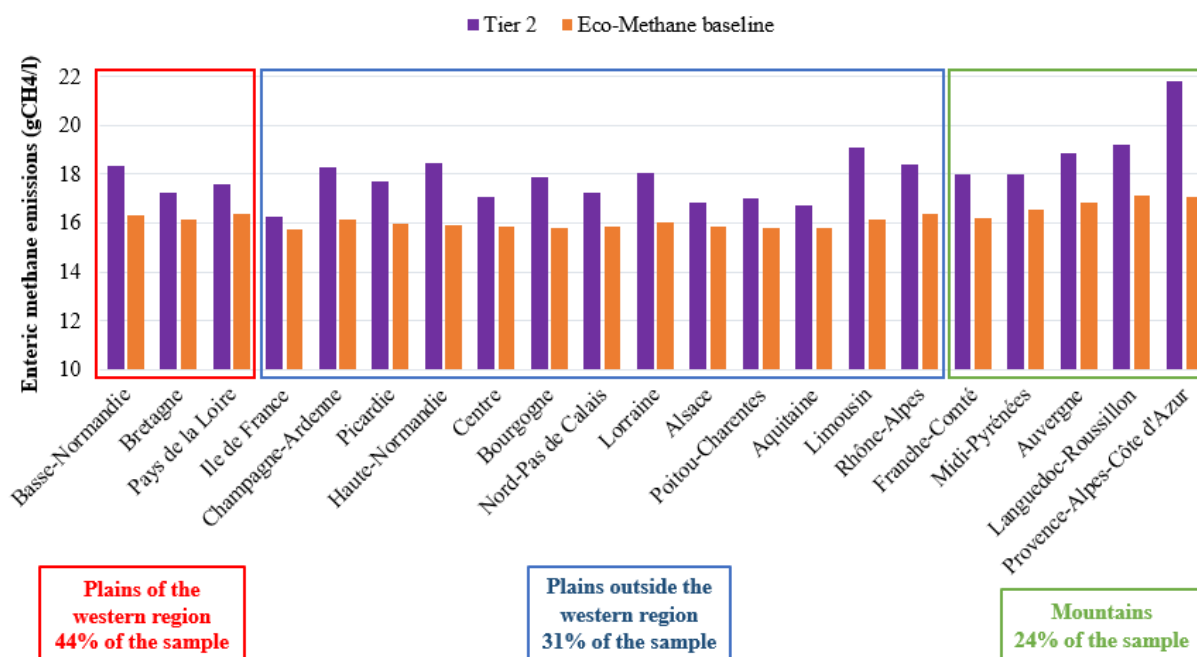
The mean of the Tier 2 indicator for the sample is 17.9 gCH₄/L, while it is 16.3 gCH₄/L for the Eco-Methane baseline indicator, suggesting that considering the fodder cropping system in the calculation revises enteric emissions downwards. Both indicators show a decrease in emissions per liter of milk as productivity increases (Table 4.4). According to indicator Tier 2, farms in mountains emit significantly more methane per liter of milk than farms in the plains, which can be explained by their lower productivity. The same observation is made with the Eco-Methane indicator, but the difference between the groups is significantly less (Table 4.4 and Figure 4.2). This finding confirms the hypothesis that a diet dominated by fodder rich in omega-3 (dairy farms typically feed cows with more grass in mountains) reduces emissions per liter of milk.

Table 4.4. Average enteric emissions of the sample according to the TIER2 and Eco-Methane baseline indicators.

Scenario	Plains outside the western region				Western plains				Mountains		
	1, 3, 5	1	3	5	2, 4, 6	2	4	6	7-11	7	8 to 11
Corn in the fodder area (%)		> 30	30-10	< 10		> 30	30-10	< 10		≥10	< 10
Sample share (%)	31.4	10.0	9.9	11.5	44.3	23.7	16.8	3.8	24.3	6.5	17.8
Productivity (L/cow)	6719.8	7654.6	6944.4	5717.8	6976.0	7331.8	6789.3	5586.5	6201.8	6910.1	5943.8
TIER2 (gCH ₄ /L)	17.92 ^a	16.83 ^b	17.59 ^c	19.15 ^d	17.60 ^{ce}	17.17 ^f	17.75 ^{ac}	19.59 ^d	18.44 ^g	17.56 ^{ch}	18.77 ⁱ
Eco-Methane baseline (gCH ₄ /L)	16.07	15.75	15.83	16.56	16.24	15.92	16.43	17.38	16.55	15.96	16.76

Mean values with different superscripts differ (p-value < 0.05).

Source: The authors, based on 2016-2018 French FADN and Bleu-Blanc-Coeur data.



Source: The authors, based on 2016-2018 French FADN and Bleu-Blanc-Coeur data.

Figure 4.2. Average enteric emissions in French regions according to the TIER2 and Eco-Methane baseline indicators.

Although the average methane emissions calculated with the Tier 2 method are not significantly different between the western plains and the other plains, their average Eco-Methane baselines are significantly different (Table 4.4). Considering the fodder crop rotation system in the calculation, enteric methane emissions are higher in the western plains. The productivity of the two groups is not significantly different, suggesting that the fodder system could explain the better environmental performance of the plains outside the western region measured by the Eco-Methane baseline indicator. As suggested by the distribution of Eco-Methane scenarios (Figure 4.1), corn silage dominates more in the western plains (32% of the fodder area on average) than in the other plains (21%). In the plains outside the western region, the feed ration of dairy cows likely includes more grass or other fodders with high omega-3 content. In addition, the lower the share of corn silage in the fodder area (and therefore, the more grasslands), the higher the difference between the emissions calculated with the two indicators.

Our observations are in line with the literature (Grainger and Beauchemin, 2011; Martin et al., 2006). A recent meta-analysis of life cycle assessments also highlighted the negative relationships between milk yield and enteric methane emissions on the one hand and pasture

intake and enteric methane emissions on the other hand (Lorenz et al., 2019). Other authors also show that enteric methane emissions particularly differ from one indicator to another in grazing systems (Hagemann et al., 2011). Choosing an adequate indicator of enteric methane emissions is the topic of ongoing debate. This analysis illustrates the importance of the choice of environmental indicator when designing a PES scheme targeting the reduction of enteric methane emissions in dairy farms, as it is likely to affect its environmental performance. We show the relevance of using an emission indicator sensitive to diet when defining economic incentives for the reduction of GHG emissions.

Detailed indicators are the most cost-effective, but due to heavy data collection needs (precise feed digestibility and composition), this advantage decreases when applied at a large scale (Lengers et al., 2013). An indicator such as the one used in Eco-Methane presents several advantages to be implemented on a large scale, and be a better proxy compared with the most widely used Tier 2 and data demanding Tier 3 indicators. It is precise enough to capture the efforts of farmers on both cow productivity and feed ration composition, and it considers the potential of an omega-3-rich diet as a climate change mitigation practice. This feeding strategy is already implemented in dairy systems integrating a large share of grasslands in their fodder crop rotation systems, with the side provision of other environmental benefits (biodiversity maintenance). Additionally, the fatty acid composition of milk provides information on the complementary health benefits for consumers of an increase in sources of omega-3 fatty acids in the diet of dairy cows (Weill et al., 2002). The accuracy of indicators based on milk analyzes could be further improved by controlling for factors likely to affect the correlation between milk fatty acid composition and enteric emissions such as the lactation stage (Negussie et al., 2017).

Furthermore, the environmental performance of PES schemes specifically targeting enteric methane emissions depends on the absence of negative spillovers on other factors of GHG emissions in dairy farms (fertilization management, machinery...). Decreasing enteric methane emissions per liter of milk is a lever particularly interesting to rapidly reduce the contribution of dairy farming to climate change while also considering the food security dimension as it refers to the quantity of food produced. But it should be complementary to further farm-level and area-based assessments of GHG emissions to support effective mitigation strategies.

4.5.3. Impact of increasing the grassland area on the marginal cost of milk production

Several model specifications were tested, and the results are robust to a change (single variable costs equation, system of equations with and without imposing constraints on the parameters for ensuring homogeneity of degree 1). The estimation of variable input shares provides additional information and improves the quality of the variable cost estimation (measured by R^2). Consistent with the hypothesis of cost minimization, imposing restrictions on the parameters across equations also improved the variable cost estimation quality. Therefore, we present the results of the constrained system estimation. All the reported first-stage F-statistics were above 10, suggesting no weak instruments.

We verify that the variable cost function is nondecreasing with input prices (positive estimated variable input cost shares). However, some of the empirical models do not respect all the theoretical properties of a cost function. In particular, variable costs are decreasing with at least one quasifixed factor of production only in the model applied to the entire sample and for the subsample of plain farms with less than 30% corn silage in the fodder area.

The first-order derivative of the variable cost function (4.5) gives the marginal cost function (4.8), in which parameter ρ_{11} corresponds to the effect of grassland surfaces on the marginal cost of milk.

$$\frac{\partial VC_{it}}{\partial Y_{1it}} = \frac{VC_{it}}{Y_{1it}} \left(\beta_1 + \beta_{11} \ln Y_{1it} + \sum_{h=1}^3 \rho_{1h} \ln Z_{hit} + \zeta_{12} \ln \frac{W_{2it}}{W_{1it}} \right) \quad (4.8)$$

The results presented in the following paragraphs are calculated from the regression results detailed in the Appendix A7.

When applied to all farms of the sample and on the subsamples of farms from the two plain production basins, the model suggests that producing milk with more grass does not significantly affect variable costs (Table 4.5). There are significant extra costs per additional hectare of grassland in mountainous areas (+3.6€/1000L/ha) already facing high marginal production costs and lower productivity.

Table 4.5. Extra-costs of milk production with an increase in grassland area

	France	Plains of the western region	Plains outside the western region	Mountains	Plains with more than 30% of corn in the fodder area	Plains with less than 30% of corn in the fodder area
Eco-Methane baseline (gCH ₄ /L)	16.26	16.24	16.07	16.55	15.87	16.41
Productivity (L/cow/year)	6708	6976	6720	6202	7427.4	6422.2
Marginal cost (€/1000L)	274.2	166.7	286.0	302.5	211.8	231.2
Extra-cost (€/1000L/ha)	0.41	7.74	-0.17	3.59 ⁺	-11.64	7.08 ^{***}
Variable cost regression R ²	0.81	0.43	0.86	0.79	0.75	0.76

⁺ p < 0.10, * p < 0.05, ** p < 0.01, *** p < 0.001.

Source: The authors, based on 2016-2018 French FADN and Bleu-Blanc-Coeur data.

Behind the nonsignificant extra costs found in plain production basins lies a disparity depending on the type of fodder system (Table 4.5). Considering all plain farms (within and outside the western region), we compare the farms with a share of corn silage in the fodder area greater than 30% to the farms with a corn silage share of less than 30%. Extra-costs are significantly lower when the share of corn is high (or the share of grasslands low). Indeed, we find nonsignificant extra costs per additional hectare of grass for farms with more than 30% of corn in the fodder area but positive additional costs of 7.1€/1000 L/ha for the farms with less than 30%. Again, extra production costs per hectare of grass are lower for farms with higher productivity and lower marginal costs.

Our results suggest that the financial needs for dairy farms to incorporate more grass in their fodder crop rotation system are different from one system to another. In particular, dairy farms with already high shares of grasslands might require higher levels of economic incentives to adopt this climate change mitigation lever. The sources of additional variable costs can be an increase in energy consumption (machinery) and other expenses (seeds, fertilizers, etc.) related to pastures and alfalfa management. Joining a PES scheme and producing milk with more grasslands by replacing hectares of cereals with grass or by increasing the fodder area with new grass plots could represent a positive economic incentive in the most intensive lowland farms

for which we observe non-significant extra-costs. Current dominant fodder systems involve high expenditures on specific corn inputs (seeds, herbicides, etc.) and high protein content complements (soya, rapeseed) to balance dairy cow feed rations. Adding more grass and benefiting from a PES would reduce dependence on costly inputs. Synergies between the reduction of GHG emissions and the economic performance of intensive dairy farms have already been pointed out in the literature (Borreani et al., 2013; Jayasundara et al., 2019). Moreover, other authors found evidence of differences in emissions abatement costs among dairy farms according to their geographical location (Njuki and Bravo-Ureta, 2015). It shows the relevance of considering the variability of dairy systems when studying the willingness of farmers to accept entering a PES programme, as we find different extra production costs linked to the modification of fodder crop rotations (increase in grassland area). Not considering the feeding strategy of dairy farmers, and in particular the type of fodder system, would lower the attractiveness of a payment scheme. It would be relevant to consider this heterogeneity when establishing an optimal payment for environmental services.

Given the low level of payment in current PES schemes (for instance in the Eco-Methane programme), it seems reasonable to assume that participating farms already had good economic profitability and/or feeding practices compatible with emission reductions when entering the programme. In the prospect of engaging more farmers and more liters of milk in the feed ration transition, we identify three types of dairy farms that could integrate a PES for the reduction of enteric methane emissions. Farms for which reducing enteric emissions is already profitable (no or negative extra costs) (type 1), farms for which it requires little financial support (low but positive extra costs) (type 2), and farms for which it requires high financial support (high positive extra costs) (type 3). Our study suggests that French plain-intensive farms broadly correspond to type 1. Although their individual willingness to accept is likely to be low, the programme would still need important financial means to offer a payment given the large number of unit of emissions reductions to compensate (high milk productivity). In contrast, dairy farms located in mountainous areas or with a high share of grasslands are more likely to correspond to type 3 and exhibit a high individual willingness to accept. Attracting them into the programme would require a high level of payment per CO₂eq for fewer units (lower milk productivity). For those farms, increasing milk productivity might be a cheaper lever to reduce enteric emissions per liter. Most French dairy farms are likely to be type 2, with an intermediate individual willingness to accept the programme but a large number of emission reduction units to compensate given the large number of potential participants.

The positive effect of grass on methane emissions is likely to be partly offset by a drop in the productivity of the cows. Other sources of omega-3 fatty acids such as linseed could also be integrated in the feed ration to maintain productivity (Fuentes et al., 2008). Feed complementation is however likely to be a more expensive lever to implement for most farmers, as they are often not produced in farms. Due to the absence of data, the extra-costs of increasing the use of omega-3 sources rich complements could not be estimated. Furthermore, for the Eco-Methane payment to efficiently subsidize the reduction of enteric methane emissions through an increase in grassland areas, the payment will have to cover both the additional costs per liter of milk and the other extra costs per hectare of grass. Beyond impacting production costs per unit of milk, a new hectare of grassland can have a direct effect on farm costs. In this study, we consider only variable costs (intermediate consumption). There may also be fixed costs (specific machinery for grass cultivation, buildings for storage) or other constraints (access to land) increasing the overall extra costs of participation. A study considering all farm costs (variable and fixed costs) found higher GHG emissions abatement costs per liter of milk in large farms (with a high number of dairy cows) compared with smaller farms (Njuki et al., 2016).

4.6. Conclusions

Two aspects of PES design for reducing enteric emissions per liter of milk are particularly crucial to favor its environmental performance. First, the choice of emission indicator should measure farmers' efforts on both cows' productivity and diet, while being easily and regularly implemented on farm at low cost. Second, evaluating farmers' willingness to accept and its variability according to farm type is necessary to define the optimal payment level and scheme's budget ensuring sufficient participation. For a given production level, producing milk with more grass have a different impact on milk variable production costs depending on the production basin and fodder system. This research provide more insights into the impact of methane emissions reduction on the production costs of livestock farms, and how to improve support for pressing abatement measures and contribute effectively to achieving climate targets.

Chapter 5. How can labeling for health concerns improve environmental public good provisioning?

This chapter addresses the issue of the underprovision of environmental public goods through the market. Value-chain included payments for environmental services (PES) aim at capturing the willingness to pay for environmental services (ES) of the stakeholders along the food chain, by differentiating goods produced with environment-friendly practices from those produce with so-called “conventional” practices. Through environment-friendly purchasing choices, which often involve the payment of a price premium, actors of the value-chain, and eventually consumers of food products send a price signal to farmers and boost ES jointly provided with agricultural products. Food labelling in particular, help consumers make more environment-friendly consumption choices with information on the agricultural practices implemented for producing the goods available on the market. Contrary to dedicated schemes, value-chain included PES can not only capture the willingness to pay for ES, but also the type of food product, and any other characteristic attached to the private good that consumers value and are aware of. Therefore, developing this payment channel represents an opportunity to raise additional (indirect) contributions from consumers to ES provision.

This chapter focuses on the environmental performance of labeling strategies to promote an agricultural commodity characterized by the joint and complementary provisioning of a global environmental public good and a superior private characteristic, such as health benefits. In a theoretical analysis based on the impure public good model, we explore different market settings with an environmental label, a health label, and a label promoting both health and the environment. We model how the degree of information on public and private characteristics provided to consumers affects public good provisioning, and derive the conditions for an optimal provision. A simulation is performed to illustrate the impact of consumer preferences on the provisioning of environmental services at the market equilibrium.

This chapter was co-authored with Elodie Letort (INRAE, SMART) and Pierre Dupraz (INRAE, SMART), and involved the following individual contributions: Elodie Letort: conceptualisation, investigation, methodology, formal analysis, validation, original draft; Fanny Le Gloux: conceptualisation, investigation, methodology, formal analysis, validation, original draft; Pierre Dupraz: conceptualisation, supervision, validation. Results were presented

at the 3rd Annual Workshop of the EDGE Economics & Management Doctoral School (15th April 2021, online), at the 10th Annual Conference of the Italian Association of Agricultural and Applied Economics (9th-10th June 2021, online), and at the 26th Annual Conference of the European Association of Environmental and Resource Economists (23rd-25th June 2021, online). The analyses also contributed to the deliverable D4.4 (Zavalloni et al., 2022) of the CONSOLE project (<https://console-project.eu/>).

5.1. Introduction

The development of organic agriculture in the 2000s inspired economists to evaluate consumers' willingness to pay for agricultural food products with environmental labels (eco-labels). Even if there is a willingness to pay for environmental factors (Teisl et al., 2002), the literature largely pointed out that consumers' motivations were not purely altruistic and associated with strong environmental sensitivity. If consumers perceive that an environmentally friendly process guarantees food safety, then the perceived benefits from the environmental attributes may also be private (Bougherara and Combris, 2009). The existing research shows that health factors are the main motives (among others, Magnusson et al. 2003; Verhoef 2005; Aldanondo-Ochoa and Almansa-Sáez 2009; Brécard et al. 2012) for consuming organically produced food products. Other papers have found that environmental preferences matter more in the decision to purchase organic products, with health concerns still having a high and significant impact (Durham, 2007). Based on these findings, several studies have reinforced the importance of encouraging ecofriendly purchases by promoting their positive effects on health. Dabbert (2006) concludes that attempts to sell organic products based only on their environmental characteristics are likely to fail, while providing information about the private benefits (such as the health benefits), as a secondary aspect, can have a positive effect on sales. Rousseau and Vranken (2013) show that after providing additional objective information on the environmental and health effects of organic apple production, the price premium consumers were willing to pay for organic apples increased from 33 eurocent to 57 eurocent per kilogram. In the context of multiple signals, labels can reinforce or attenuate each other (Grolleau and Caswell, 2006; Onozaka and McFadden, 2011).

The new instruments put in place by the European Green Deal also show such a trend. The new European Farm to Fork Strategy that could guide and support transformation paths toward more sustainable agricultural practices includes actions for transforming European food systems, including the development of a food-labeling framework to promote healthy and environmentally friendly food consumption (EC, 2020a).

To our knowledge, whether promoting private characteristics, such as the health benefits, of goods produced from environmentally friendly practices can increase the provisioning of public goods has not been demonstrated. In this paper, we theoretically assess the potential of labels that target health and environmental aspects and show that such labels may improve the delivery of environmental public goods compared with environmental labels.

The main condition on this result is the joint provision of private health and public environmental benefits that can occur with agricultural commodities produced using environmentally friendly agricultural practices. Indeed, crop management practices can impact the nutritional composition of agricultural products (Hornick, 1992) and the environment (Tuomisto et al., 2012). Livestock feeding practices can also affect the composition of animal products and greenhouse gas emissions. For instance, dairy cows fed a higher percentage of grass fodder or extruded linseed both produce milk with a higher omega-3 content, which is recommended for a healthy diet (Weill et al., 2002) and decreases enteric methane emissions per liter of milk (Weill et al., 2009). Consumers have a willingness to pay for food, health and the environment. When joint provision arises, providing information on complementary private benefits could be effective in attracting additional consumers to contribute to environmental public good provisioning (Grolleau et al., 2009).

The rest of the paper is organized as follows. We start with a description of our theoretical framework, which is inspired by the impure public good model of Kötchen (2005). In the second part, we present the optimal conditions that characterize this economy from a social planner's perspective and an environmental or health agency's perspective. In the third and fourth sections, we derive the different market equilibrium conditions according to the level of information available to the consumer when an environmentally friendly product is labeled based on its private characteristic (health label), public characteristic (environmental label), or both (health and environment label). We then compare the different market settings in terms of environmental public good provisioning and distance to social and environmental optimality based on a simulation in the fifth section. Section six provides a conclusion.

5.2. Preliminaries

We start from a theoretical framework in which the utility function of consumers depends on the characteristics of the goods. This approach is widely used to model consumer behavior (Gorman, 1980; Lancaster, 1966), particularly in models of impure public goods (Cornes and Sandler, 1994; Kötchen, 2005). In this analytical framework, green products are impure public goods that generate both a private characteristic and a public characteristic. Kötchen (2005) considers that the consumer has a choice between two goods, a conventionally produced good, which generates a private characteristic, and a green good produced from environmentally

friendly practices, which generates the same private characteristic as well as a public characteristic (the improvement of the quality of the environment). He also provides substitutes for the green product. Consumers can obtain private characteristics by buying conventional products or green products and public characteristics by buying green products or by making a direct donation to the corresponding environmental cause. Van't Veld and Kotchen (2011) consider that the green product brings an additional private benefit to the consumer compared to the conventional product. On the other hand, they assume that consumers' willingness to pay for this green product depends only on the private benefit associated with its consumption, since all consumers can benefit from the public benefits (free-ride behavior).

Following these works, we consider two food products, a conventional good c and a green good g . These two goods generate the same private characteristic X , which corresponds to the need to feed oneself. The green good g generates the private characteristic X as well as two additional characteristics, a public characteristic Y and another private characteristic H . Since the good g is produced by more environmentally friendly agricultural practices, it is assumed that its production and consumption allow for the improvement of the quality of the environment corresponding to the public good Y . The originality of our approach is that the nutritional qualities of the green good g are superior or less chemical products are required for its production compared with conventional good c . Thus, the consumption of good g improves the health of the consumer, which is a private characteristic H .

We consider $i = 1, \dots, I$ consumers. Each individual's preferences are represented by a strictly increasing and strictly quasi-concave utility function $U_i(X_i, Y, H_i)$, where X_i and H_i are individual i 's private consumption of characteristics X (food product) and H (health benefits), and Y (environmental benefits) is the provisioning of the public characteristic such that $Y = \sum_i^I Y_i$, where Y_i is individual i 's private contribution. For each individual, the contribution of others to the public characteristic is exogenous, such that $Y = Y_i + \sum_{j \neq i}^I Y_j = Y_i + Y_{-i}$.

The question we sought to answer is whether the information given to consumers on food products impacts the provision of environmental public goods. More specifically, we want to know if the valorization of products for their benefits for health is an approach to be encouraged in the framework of environmental policies. Therefore, we compare three market settings for a same green product g (Table 5.1) that differ only by the information given to consumers on the green product. This information will modify their consumption choices according to their

preferences and potentially influence the provision of environmental public goods. Our framework is based on the assumption that the label is the only way for consumers to obtain information about goods. We consider that there are no other types of information that can change consumers' perceptions. Depending on whether there is a label or not, the consumer does not perceive the same information on this good, although this one keeps the same characteristics.

Table 5.1. Different market settings compared in the paper.

Market settings	Goods	Characteristics known by consumers
Environmental label	good c	private characteristic X
	good g	private characteristic X and public characteristic Y
Health Label	good c	private characteristic X
	good g	private characteristics X and H
Health & environment label	good c	private characteristic X
	good g	private characteristics X and H and public characteristic Y

Source: own elaboration.

In the first market, with the environmental label, consumers know that good g is produced using environmentally friendly practices. They have no a priori information on its health benefits. The second market offers a conventional product and a product with a label guaranteeing health benefits. Consumers know that good g provides higher health benefits than good c ; however, they have no information on the environmental impact of the agricultural practices associated with their production. In the third market, we assume that the information is complete for consumers based on its label, which identifies both the environmental and health benefits of the product g .

Each individual i can allocate his wealth r_i to purchase a quantity c_i of conventional good c at price p_c and a quantity g_i of impure public good g at price p_g , such that $p_c c_i + p_g g_i \leq r_i$. It is assumed that $p_g > p_c$ to ensure the viability of the conventional good on the market, which implies that buying good c is the most inexpensive method of obtaining private characteristic X .

Regarding agricultural technologies, buying one unit of c leads to the provision of one unit of X while buying one unit of g leads to the provision of one unit of X , α units of H and β units of Y , with $\alpha > 0$ and $\beta > 0$. These technological parameters are considered exogenous and known to all consumers when this information is provided on the product label. The relation between the quantities of goods c_i and g_i and the consumption of the characteristics X_i , H_i and Y_i is then defined by $X_i = c_i + g_i$, $H_i = \alpha g_i$ and $Y_i = \beta g_i + \beta g_{-i}$. Given these relations, the utility function can be rewritten as follows: $U_i(c_i + g_i, \alpha g_i, \beta g_i + \beta g_{-i})$. We consider an economy with production to obtain the market equilibria (and not just consumer equilibria). Even if our paper focuses on the analysis of consumer behavior, it is interesting to consider the behavior of producers when discussing the assumptions made about production technologies. In addition, the analytical framework we propose could be used in further research to focus on producer behavior. Here, we consider one representative producer who produces the two goods c and g , subject to technological constraints represented by $T(c, g) = 0$. Since $p_g > p_c$, the marginal cost of producing good g must be greater than the marginal cost of producing good c to prevent the producer from producing only good g .

5.3. Optimal regulation of our economy

In this section, we describe the optimal conditions that characterize our economy from the perspective of a social planner, an environmental agency and a health agency. The social planner seeks a Pareto optimal outcome by considering both the health and environmental characteristics of the food products. In contrast, we assume that the environmental agency seeks to optimize the total utility of the consumers without considering the health benefits of the products while the health agency seeks to optimize the total utility without considering the environmental benefits of the products.

5.3.1. Social optimum

If a social planner could choose the optimal level of public good provision, he would maximize social welfare corresponding to the sum of the individual utility and solve the following problem:

$$\max_{c, g} \{ \sum_i U_i | c = \sum_i c_i, g = \sum_i g_i, T(c, g) = 0 \}. \quad (5.1)$$

At the optimum, the sum of the quantities of goods c and g consumed by all individuals is equal to the quantity of goods produced by the producer according to the production technology $T(c, g)$. The derivation of this program leads to the following first-order conditions:

$$\frac{\partial U_i}{\partial X_i} = \lambda \frac{\partial T(c, g)}{\partial c} \quad (5.2)$$

$$\frac{\partial U_i}{\partial X_i} + \alpha \frac{\partial U_i}{\partial H_i} + \beta \frac{\sum_i \partial U_i}{\partial Y} = \lambda \frac{\partial T(c, g)}{\partial g} \quad (5.3)$$

where λ is the Lagrangian multiplier associated with production technology. Combining these two conditions leads to the Pareto optimum condition:

$$\frac{\alpha \partial U_i / \partial H_i^p + \beta \sum_i \partial U_i / \partial Y^p}{\partial U_i / \partial X_i^p} = \frac{\partial T(c, g) / \partial g}{\partial T(c, g) / \partial c} - 1. \quad (5.4)$$

Where X_i^p , H_i^p and Y^p correspond to the Pareto optimal demand for private and public characteristics of goods g and c . The Pareto optimum requires that the sum of the marginal rates of substitution between characteristics, weighted by technology parameters α and β , be equal to the marginal rate of transformation. The term on the right-hand side of equation (5.4) represents the marginal rate of the transformation of goods, i.e., the quantity by which the production of the good c must be reduced to produce an additional unit of the other good g . The terms $\frac{\partial U_i / \partial H_i^p}{\partial U_i / \partial X_i^p}$ and $\frac{\partial U_i / \partial Y^p}{\partial U_i / \partial X_i^p}$ correspond to the marginal rate of substitution between two characteristics, i.e., the change in the quantity consumed of one characteristic required to keep its utility constant following a change in the quantity consumed of the other characteristic. In the presence of a public good, we have to consider the sum of the marginal willingness to pay for this public good over all consumers since the quantity of public good consumed is the same for all (Bowen-Lindahl-Samuelson condition) (Samuelson, 1969, 1954).

5.3.2. Environmental agency's optimum

If an environmental agency has the ability to choose the optimal level of public good provision, it would only consider food production X_i and the public good Y jointly produced with g . The optimal condition for an environmental agency corresponds to the optimal condition (Equation (5.4)) with $\alpha = 0$ since this agency does not consider the health benefits of consumption of good g .

$$\beta \sum_i \frac{\partial U_i / \partial Y^{ea}}{\partial U_i / \partial X_i^{ea}} = \frac{\partial T(c,g) / \partial g}{\partial T(c,g) / \partial c} - 1 . \quad (5.5)$$

Where X_i^{ea} and Y^{ea} correspond to the optimal demand from the environmental agency perspective for private and public characteristics of goods g and c . The sum of the marginal rates of substitution between public and private characteristics must be equal to the marginal rate of transformation between public and private goods. Note that this condition is also the Pareto optimum condition associated with the model of green consumption defined by Kötchen (2005), which does not consider the private characteristic H_i . The corresponding private consumption H_i^{ea} is obtained from $\sum_i H_i^{ea} = \alpha g^{ea*}$ when g^{ea*} solves the optimization program of the environmental agency.

In the presence of a private good and a public good, state intervention, such as by an environmental agency, is justified to ensure the provision of the public good. Assuming perfect information from the state, the optimal provision of Y could be achieved by collecting a tax equal to $\sum_i \frac{\partial U_i / \partial Y^{ea}}{\partial U_i / \partial X_i^{ea}}$ on consumers' income to subsidize the production of good g . In this case (and in theory), the provision of public good would be optimal according to the condition defined in equation (5.5). In practice, the state has only imperfect information, notably concerning the costs of providing a public good and the willingness of consumers to pay. Then, the real provision of the public good is below its optimal level.

5.3.3. Health agency's optimum

If a health agency had the ability to choose the optimal level of public good provision, it would only consider food production X_i and the private good H_i jointly produced with g . The optimal condition for a health agency corresponds to the optimal condition (Equation (5.4)) with $\beta = 0$ since this agency does not consider the environmental benefits of consumption of good g .

$$\alpha \frac{\partial U_i / \partial H_i^{ha}}{\partial U_i / \partial X_i^{ha}} = \frac{\partial T(c,g) / \partial g}{\partial T(c,g) / \partial c} - 1 . \quad (5.6)$$

Where X_i^{ha} and H_i^{ha} correspond to the optimal demand from the health agency perspective for private and public characteristics of goods g and c . The marginal rates of substitution between the two private characteristics must be equal to the marginal rate of transformation between the

two goods. The corresponding public consumption Y^{ha} is obtained from $Y^{ha} = \beta g^{ha*}$ when g^{ha*} solves the optimization program of the health agency.

Compared with the environmental agency, the health agency has no role to play and does not need to intervene in this market as long as information on the health benefits of an agricultural product is given to consumers, since any market equilibrium is Pareto optimal in a market characterized by private goods. Consumer demand for characteristic H is therefore optimal without state intervention. If health information is not provided, the health agency can intervene, for instance by taxing unhealthy food consumption (Allcott et al., 2019; Griffith et al., 2018).

5.4. Equilibria under different levels of information

In this section, we derive the different market equilibria according to the level of consumer information on the products and compare these equilibria to the regulators' optima defined in the previous section. The benefits on the environment and health associated with the consumption of goods are present in each economy. The three market settings only differ in terms of the information available to consumers (label).

5.4.1. Health and environment label

This part presents the market equilibrium conditions under complete information provided by a label that identifies the environmental and nutritional qualities of product g (health and environmental label). In this first market setting, each consumer i maximizes his utility function under his budget constraints:

$$\max_{c_i, g_i} \{U_i \mid p_c c_i + p_g g_i \leq r_i\}. \quad (5.7)$$

The first-order conditions are derived from the characteristics of the goods c_i and g_i , which are all known by consumers. The derivation of this model leads to the following first-order conditions:

$$\frac{\partial U_i}{\partial x_i} = \lambda p_c, \quad (5.8)$$

$$\frac{\partial U_i}{\partial X_i} + \alpha \frac{\partial U_i}{\partial H_i} + \beta \frac{\partial U_i}{\partial Y} = \lambda p_g. \quad (5.9)$$

As prices are equal to marginal costs, the market equilibrium conditions are defined as follows:

$$\frac{\alpha \partial U_i / \partial H_i^{eh} + \beta \partial U_i / \partial Y^{eh}}{\partial U_i / \partial X_i^{eh}} = \frac{\partial T(c,g) / \partial g}{\partial T(c,g) / \partial c} - 1, \quad (5.10)$$

where X_i^{eh} , H_i^{eh} and Y^{eh} correspond to the demand for private and public characteristics of goods g and c at equilibrium in a market characterized by health and environment label. The willingness to pay for the health and environment labelled product is equal to the sum of the marginal utility of the health characteristic and the marginal utility of the public characteristic. In the case of a single consumer, this equilibrium condition coincides with the socially optimal condition defined in equation (5.4). In this case, the full information equilibrium is then socially optimal. In other words, the inefficiency of the full information equilibrium in the case of several consumers only comes from the absence of considering the externality created by g_i by each consumer on the others, as we can see from the formulation. When comparing equation (5.10) to the optimality condition of the environmental agency (5.5), we notice that the environmental efficiency of the health and environment label will depends on the relative marginal utilities of the health and environmental characteristic, while the health and environment label reaches the optimal amount of health provision targeted by a health agency (Equation (5.6)).

5.4.2. Environment label

In the second market setting, we assume that consumers know that good g is produced using environmentally friendly practices. However, they have no a priori information on the health benefits of the product, although they exist. Each consumer i maximizes his utility function under his budget constraint. The first-order conditions are derived only in relation to the product characteristics known by the consumers, i.e., X_i and Y . These conditions, which are associated with the producer's equilibrium, lead to the following market equilibrium condition:

$$\beta \frac{\partial U_i / \partial Y^e}{\partial U_i / \partial X_i^e} = \frac{\partial T(c,g) / \partial g}{\partial T(c,g) / \partial c} - 1, \quad (5.11)$$

where X_i^e , H_i^e and Y^e correspond to the demand for private and public characteristics of goods g and c at equilibrium in a market characterized by an environmental label. These conditions

also correspond to the market equilibrium of the green consumption model of Kötchen (2005). Each agent does not consider that the financed public good provision also benefits other agents. Agent i contributes to providing the public good until the marginal cost of the private good is equal to its marginal rate of substitution. Consequently, consumers as a whole contribute less to the public good than what would be desirable to achieve Pareto optimality or the environmental agency's optimality.

5.4.3. Health label

In this third market setting, we assume that consumers know that good g has superior nutritional qualities compared with good c but have no information on the environmental impact of the agricultural practices associated with the production process. Each consumer i maximizes his utility function $U_i(X_i, Y, H_i)$ under his budget constraint (5.7). The first-order conditions are derived in relation to the product characteristics known by the consumers, i.e., X_i and H_i . These conditions, which are associated with the producer's equilibrium, lead to the following market equilibrium condition:

$$\alpha \frac{\partial U_i / \partial H_i^h}{\partial U_i / \partial X_i^h} = \frac{\partial T(c, g) / \partial g}{\partial T(c, g) / \partial c} - 1 \quad , \quad (5.12)$$

where X_i^h and H_i^h correspond to the demand for private and public characteristics of goods g and c at equilibrium in a market characterized by a health label. Classically, the market equilibrium leads to the optimal provision of private characteristics from the perspective of a health regulator (see Equation (5.6)).

Even if consumers do not have information on the positive environmental externality associated with their consumption, the public good Y is provided jointly with the production of good g . The quantity of public characteristics Y provided through the consumption of good g is thus equal to the sum of the quantities of private characteristics H_i consumed by all consumers multiplied by the ratio of the technology parameters, such as the following:

$$Y^h = \frac{\beta}{\alpha} \sum_i H_i^h. \quad (5.13)$$

This equation reflects the jointness of production between environmental and health characteristics, with the ratio β/α corresponding to the intensity of this jointness. Substituting

this last equation into the equilibrium condition (5.12), we obtain a new condition depending on the level of the public characteristic:

$$\beta \sum_i \frac{\partial U_i / \partial Y^h}{\partial U_i / \partial X_i^h} = \frac{\partial T(c,g) / \partial g}{\partial T(c,g) / \partial c} - 1. \quad (5.14)$$

The market equilibrium does not correspond to a Pareto optimal allocation. Nevertheless, recalling the environmental agency optimum (Equation (5.5)), the market equilibrium of the health label leads to the optimal public good provision from the perspective of an environmental regulator under specific conditions (including the same level of preference for health and the environment). These conditions will be described in Section 5.5.

5.5. Comparison of public good provision

In this section, we assume a functional form of the utility function to compare the level of public good provision from the three types of labels (environmental label, health label, health and environment label) for a same product. We also perform a simulation to observe the evolution of the provision of public goods at the equilibrium of the different market settings according to the consumers' levels of preference for health and environmental benefits.

5.5.1. Public good demand function

To facilitate the comparison between the different market equilibria derived in the following sections and the optimality conditions, we assume that consumers are homogeneous and the utility function has a functional form as follows:

$$U_i(X_i, Y, H_i) = \theta_X \ln X_i + \theta_Y \ln Y + \theta_H \ln H_i. \quad (5.15)$$

where θ_X , θ_Y and θ_H correspond to the preference parameters for food, environment and health factors, respectively. This utility function is strictly increasing, twice continuously differentiable and strictly quasi-concave. This type of functional form, such as Cobb–Douglas preferences, considers homothetic preferences, which is classically assumed when deriving aggregate consumer demand from the utility maximization behavior of a representative rational consumer (Caselli and Ventura, 2000).

As previously defined, Y^e , Y^h and Y^{eh} correspond to the equilibrium provisioning of a public good with an environment, a health label, and a health and environment label, respectively.

$$Y^e = \beta \left(\frac{\theta_Y/I}{\theta_X + \theta_Y/I} \right) \left(\frac{1}{p_g^e - p_c^e} \right) \sum_i r_i \quad (5.16)$$

$$Y^h = \beta \left(\frac{\theta_H}{\theta_X + \theta_H} \right) \left(\frac{1}{p_g^h - p_c^h} \right) \sum_i r_i \quad (5.17)$$

$$Y^{eh} = \beta \left(\frac{\theta_Y/I + \theta_H}{\theta_X + \theta_Y/I + \theta_H} \right) \left(\frac{1}{p_g^{eh} - p_c^{eh}} \right) \sum_i r_i \quad (5.18)$$

The weight of preferences for health and/or environment, which are represented by a ratio depending on θ_X , θ_Y and θ_H , has an important impact on the level of public good provided by the three types of labels. This ratio describes the consumers' willingness to pay for these characteristics. With the environmental label, the market failure is such that the preference for the environment θ_Y is individualized (Equation (5.16)). Consumers do not consider the willingness of other consumers to pay for this public characteristic. Rather, they only consider their willingness to pay, which is translated in the model as a level of preference divided by the number of consumers (θ_Y/I). In an optimal situation from an environmental agency's perspective, the ratio of preferences would be equal to $\theta_Y / (\theta_X + \theta_Y)$. The level of public good provided with an environmental label is therefore much lower than those provided in optimal situations (all the more so as the size of the market is large). In contrast, in the case where $\theta_Y = \theta_H$ and prices of goods are the same across market settings, the level of public good provided by the health label is optimal in the sense of an environmental agency (Equation (5.17)). The provision of public good by the health and environment label (Equation (5.18)) also suffers from an underestimation of the consumers' willingness to pay for Y . Similar to the environmental label, preferences for the environment appear individualized. On the other hand, consumers' willingness to pay for health greatly increases the supply of public goods, and the provision of public good can reach the optimal amount targeted by an environmental agency under certain conditions of relative preferences for health and the environment.

When information is incomplete and consumers only have access to information on one of the two complementary characteristics (environmental label or health label), more public goods are provided through the market of a health label in most situations. Assuming identical prices between the environment-labeled and health-labeled good g , an environmental label leads to

higher provisioning of the public good only for a case characterized by a very small market associated with a significantly higher preference for environmental characteristics than health characteristics (dividing the expression of Equations (5.16) and (5.17) leads to the condition $\theta_Y / \theta_H > I$, in which the environmental label provides more public good). Under perfect information (health and environment label) and when consumers exhibit preferences for the three characteristics ($\theta_X, \theta_Y, \theta_H > 0$), the provision of the public good is always higher than the market outcomes of an environmental label or a health label.

Our analysis shows that preference parameters influence market outcomes. This is an expected result because the impact of individual preferences has been highlighted in numerous studies on consumer demand and differentiated market efficiency (Aldanondo-Ochoa and Almansa-Sáez, 2009; Brécard et al., 2012, 2009; Lusk et al., 2007; Moon et al., 2002; Schifferstein and Ophuist, 1998). This literature also emphasizes that consumer preferences are heterogeneous. Moreover, consumers with high preferences for the environment may have different socioeconomic characteristics than those with high preferences for health. On the one hand, willingness to pay for environmental attributes increases with income, altruism, education and environmental awareness and decreases with age (Aldanondo-Ochoa and Almansa-Sáez, 2009; Brécard et al., 2009; Lusk et al., 2007; Moon et al., 2002). On the other hand, willingness to pay for health attributes decreases with education and increases with age (Brécard et al., 2012; Govindasamy and Italia, 1999; Schifferstein and Ophuist, 1998). In this section, we do not account for this heterogeneity, although we know it exists. We focus on the market outcome considering the behavior of a consumer representative of the average preferences of the population. Adding heterogeneity might introduce additional nuancing elements but would not affect the overall results and conclusions.

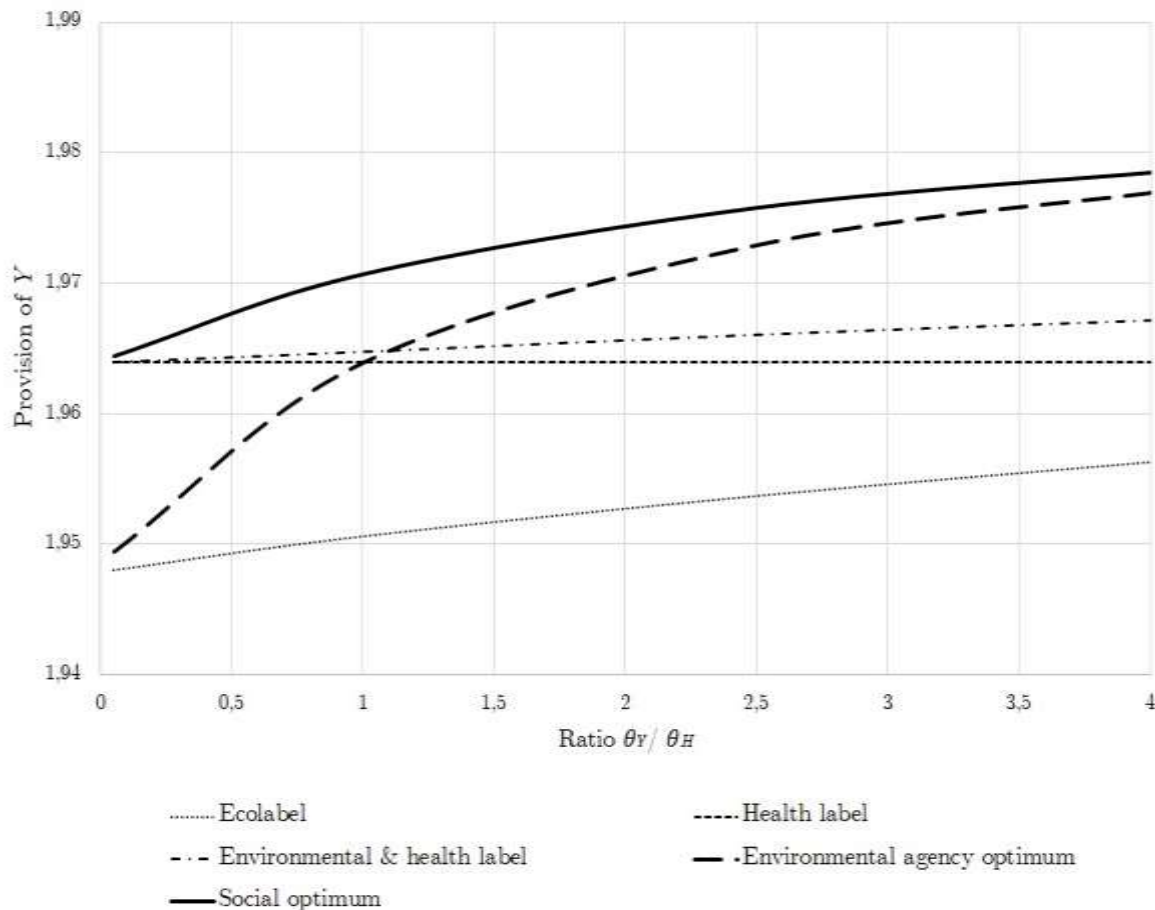
We have calculated the quantities of goods g and c at consumer equilibrium, which allows us to derive the demand for public good Y in each market characterized by a specific type of label. We observe that the demand for the public good is higher when consumers have information on the health benefits of consuming good g . However, these public good demands are not directly comparable since the prices of goods g and c are not the same from one market to another. An increase in the demand for good g will lead to an increase in the production of this good g and therefore an increase in its marginal cost, which will be borne by the producer. The selling price of good g will adjust upwards so that it equals its marginal cost. The increase in the price of good g will therefore reduce the initial demand for good g until an equilibrium

price, allowing supply and demand to be equalized, is reached. Thus, although the supply of public good will always be higher when the health attribute is valued, the difference in public good Y provided by the different labels will be mitigated by the increase in the price of good g . To compensate for this, the behavior of the producer must be considered, which will be explored in the following section using a simulation.

5.5.2. Simulations of different market equilibria

A simulation is performed to observe the evolution of the provision of Y at the equilibrium of the different markets according to the levels of preference for health and the environment of consumers. In the simulation, we consider a market of 50 consumers who each have an income of 5 to allocate to the purchase of good c and/or good g , which is produced by a single producer. We characterize the production technologies of goods c and g simply, such that several assumptions are met. First, the production of one unit of good g requires less polluting inputs than the production of one unit of good c . Second, the marginal cost of producing good g is higher than the marginal cost of producing good c . If the price of good g was less than or equal to the price of good c , good c would never be consumed. The assumptions made about production technologies are detailed in Appendix A8.

We assume that consumers have a preference θ_X for characteristic X equal to 0.8. This preference represents consumers' need for nutrition. The preference for health θ_H is set to 0.2. We vary the value of the preference for the environment θ_Y so that the ratio θ_Y / θ_H varies between 0 and 4. A ratio close to 0 means that the consumer preference for the environment is close to zero or very much lower than the consumer preference for health. A ratio equal to 1 means that the preference for the environment is the same as that for health. The higher the ratio is, the stronger the preference for the environment than for health. For each of the values of this ratio, we calculate the equilibrium prices p_c and p_g , which equalize the supply and demand in different markets and thus the level of public goods supplied. Figure 5.1. shows the evolution of public good provision at equilibrium in the three economies with labels and at the optimum (social and environmental agency) according to the ratio of preferences for the environment and health and the size of the market.



Source : own elaboration.

Figure 5.1. Simulation of public good provisions.

The environmental label contributes to providing the public good if the price of good g is low. However, even if consumers have high environmental preferences, the strength of environmental labels in stimulating the consumption of good g is lower than that of labels that show the improved nutrition/health benefits for consumers. The performance of health labels compared to the optima depends on the level of consumer preferences for the environment and health. Empirical evidence suggests that regarding food, consumer preferences for health, a private characteristic, tend to be higher than those for environmental quality (Aldanondo-Ochoa and Almansa-Sáez, 2009; Rudd et al., 2011). This suggests that $\theta_V < \theta_H$ in most actual market settings; thus, there is a real opportunity for environmental public goods provision to demonstrate and provide information on the complementary health benefits of environmentally friendly food consumption. This case is shown on the left side of the graph, where the ratio

θ_Y / θ_H is less than 1. Promoting private attributes, such as health, to stimulate the consumption of environmentally friendly products contributes to the provisioning of more Y than an alternative, such as subsidies driven by the environmental agency. Moreover, in this case, the difference with the Pareto optimal Y is the smallest.

We also show that market size does not affect the relative environmental performance of the types of labels. Indeed, with 50 consumers, the environmental label provision will start surpassing the health label provision when preferences for the environment are at least 50 times higher than for health, which is very unlikely in a real life setting. Moreover, the larger the population, the less effective the environmental label and the smaller the difference of provisions between the health and environment label and the health label. This finding suggests that adding information on the joint production of a public characteristic to a label that initially promoted a private characteristic has a negligible environmental impact in a large market.

We can imagine the implementation of an aid to producers to encourage them to have more environmentally friendly practices. In our model, this practice would correspond to a decrease in the marginal cost of production of good g . The equilibrium price of good g would therefore be lower than its price without subsidies. In all labelling scenarios, the provision of public good would be stimulated. Even if the provision of public good is always higher in the case of the health and environment label, the variation of public good provided (with and without subvention) is stronger in the case of the environmental label. An economic incentive for good agricultural practices reduces the gap between the different labels and improves the efficiency of the environmental label compared to other labels.

These results are also dependent on the characteristics of the production technologies used to produce the goods and of the producers, which are in practice very heterogeneous. A producer who can adapt to price variations by changing the quantity of inputs used and outputs produced (that correspond to a weaker parameter γ , see Appendix A8) will provide more public goods under different labels. On the other hand, a technological improvement that would increase the productivity of the less-polluting input (by further lowering the value of η_g , see Appendix A8) would not change the quantity of good g produced but would improve the environmental benefit. This would correspond to an increase in the technological parameter β , which represents the amount of public characteristics provided by the consumption of one unit of good g .

5.6. Conclusion

In this paper, we investigate the potential of markets for a healthy and environmentally friendly good to contribute to improving environmental public good provisioning. Our model applies when environmentally friendly agricultural practices jointly improve the nutritional quality (or any other intrinsic characteristic) of an agricultural product. That is, when health and environmental characteristics are complementary.

The theoretical analysis provides two main results. First, when consumers only have access to partial information on one of the two complementary characteristics (environment label or health label), only a health label leads to the optimal amount of public good provisioning from the perspective of an environmental agency under certain conditions. Second, providing full information on the public and private characteristics of the agricultural product increases the (i) environmental benefits compared with an ecolabel and (ii) environmental benefits compared with a health label. The extent of this increase depends mainly on the consumers' preferences and market size. Indeed, the difference between a health label and a health and environment label becomes less when consumer preference for health is higher than for the environment.

Our approach relies on several hypotheses. First, we assume no additional cost of labeling on two characteristics rather than one. In practice, the costs of the transaction and the costs of providing, disseminating and processing information in particular are likely to modify market outcomes in many cases. Second, our results are valid under the assumptions of convexity of consumer preferences and the production set. In particular, our assumption of homothetic preferences implies constant income elasticity of demand. For many types of food products, demands for health and environmental quality characteristics are likely to be income elastic (Clements and Si, 2018; Markusen, 2013). In a multiconsumer economy, nonhomothetic utility functions (e.g., with Stone–Geary preferences) could capture income-related effects on the demand for characteristics. One could, for example, assume there is no demand for health and/or environmental quality below a threshold income level. This would result in health labeling having an even stronger positive effect on public goods provision as population income increases. Third, we consider well-defined complementary joint production. Natural processes underlying joint production are complex and often context-dependent. Thus, it might not always be technically feasible to link an agricultural commodity to a measured health and/or environmental attribute.

The combined effects of environmental, nutritional, health and taste characteristics is a topic of many ongoing debates (Bougherara and Combris, 2009). While some complementarities are based on consumers' perceptions without scientific proof, others have been extensively studied and documented. Even if the organic label is initially an environmental label, it can be considered as a health and environment label in our analysis framework since consumers associate a private benefit related to health. Other examples of food labels based on a strict complementarity between health and environmental characteristics do exist. The French quality BBC (Bleu-Blanc-Coeur) branch provides a good illustration. The BBC label was created in the early 2000s to offer consumers differentiated animal products that provide nutritional benefits to human health by enriching the diet of livestock with sources of omega-3 fatty acids (Weill et al., 2002). In parallel to the development of the BBC market, new research has emerged showing that enteric methane emissions decline as ruminant feed is enriched with unsaturated omega-3 fatty (Dong et al., 1997; Grainger and Beauchemin, 2011; Martin et al., 2011, 2008). The availability of new information on the positive environmental impact of the BBC nutritional approach offered new perspectives. The label now communicates both the nutritional and environmental attributes of dairy products. The nutritional and environmental importance of the BBC approach has been officially recognized by the French government. Our theoretical analysis suggests that a health and environment label such as the BBC label would contribute more to methane emissions abatement than a dairy environmental label to the reduction of enteric methane emissions.

The European Commission recently presented its Farm to Fork strategy as part of the Green Deal with the objective of developing labels promoting both health and environmental benefits. Our results suggest that from an environmental policy perspective, nutritional and health labeling is a relevant tool to increase public goods provisioning and complement agri-environmental subsidies. In addition to supporting the development of labels, policy makers have a role in reducing information asymmetries regarding the reliability and accuracy of the information they carry.

Our findings highlight interesting directions for future research. In a context where consumer preferences for health are strong, knowledge on the impacts of agricultural practices on human health must be strengthened and environmentally friendly agricultural practices that produce healthy products must be encouraged. For example, labeling goods produced without pesticides, for which consumers have a real willingness to pay (Florax et al., 2005), seems to be an interesting lever for reducing the use of pesticides. Similarly, it would be interesting to

promote research on the evaluation of consumers' willingness to pay for private characteristics (nutrition, health, taste, and social value) for several types of goods produced in an environmentally friendly way. This would allow us to identify the information that should be communicated to consumers via labels.

Chapter 6. General conclusion

Environmental services (ES) refer to farmer interventions contributing to maintaining or enhancing ecosystem services. They contribute to the provision of public goods such as climate change mitigation, and water quality and biodiversity preservation, and are jointly provided with agricultural commodities. In a context of increasing scarcity and overall degradation of public good provisioning from agriculture, there is a consensus that ES are subject to market failure. In the absence of regulations, they are positive externalities currently provided at a very low level relative to the environmental challenges. Payments for environmental services (PES) are instruments aiming at correcting this underprovision. PES incentivise farmers to voluntarily maintaining or implementing agricultural practices contributing to well-functioning ecosystem services. My PhD aimed at applying empirical and theoretical microeconomic approaches to analyse the efficiency of their payment mechanisms, and in particular the two polar cases: (i) public support dedicated to agri-environment-climate measures (AECM), (ii) price premium on a joint agricultural commodity.

My PhD thesis is organised in six chapters. In the first chapter, I introduce the main concepts and definitions I use, and provide a short literature review of the different types of mechanisms of PES implemented in the European Union (EU). The next four chapters are research articles, for which I summarise the main contributions, limits and perspectives in the next sections.

I adopt the PES definition of Wunder (2015). They are voluntary transactions between ES providers and ES users conditioned to the implementation of an agreed set of rules for generating offsite services. In my PhD, I only consider PES with financial transactions (payments), and farmers as ES providers. Rather than ES users, I use the term ES contributors. They can be of many types and exhibit heterogeneous preferences and willingness to pay. From the existing schemes in the EU, we identify taxpayers at different levels (EU, national, local), consumers of food commodities, and private organisations (companies, agencies, associations...). The set of rules characterises the condition(s) for the payment to be delivered to the farmer. In particular, we can distinguish commitments on agricultural practices and/or environmental targets. On the demand side, the literature shows evidence that ES provision is largely underfunded through the existing payment channels. On the supply side, the literature reveals the inadequacy of current PES to meet ambitions, mainly from the observation that

participation of farmers is low and their environmental additionality insufficient. Low participation shows that PES are not profitable for most farmers (which can be related to low funding from the demand side). Low environmental additionality is both the result of low participation and poor instrument design. In my PhD, I study two key dimensions to increase PES effectiveness: capturing more willingness to pay from contributors, and adapting the payment mechanism to the technical problem addressed.

6.1. Main contributions

The first type of PES mechanism I analyse is public support dedicated to voluntary environmental commitments of farmers within the framework of the common agricultural policy (CAP). The main PES currently implemented in the EU are 5-years contracts for implementing AECM or organic practices. Empirical data shows that there is a gap between the stated priorities of the CAP and their relative budget. In particular, the budget dedicated to supporting environment-friendly agricultural practices is low in comparison with the budget for direct payments to farmers which have no or little environmental conditionality. In the second chapter, I study a policy lever to upscale environmental incentives and increase the uptake of public PES by farmers. I evaluate the impact of a budget transfer from direct payments towards support for the voluntary adoption of AECM and organic farming (OFS) in France. This option aims at increasing the public funding of environmental incentives without raising taxpayers' contributions. Participation in a PES results from a farm-level decision process influenced by many factors, including eligibility and the characteristics of the PES proposed by public authorities, and farm characteristics. We further assume it can be affected by interactions with price signals from other CAP instruments. We apply a generalised Tobit to model farmers' voluntary adoption of AECM and OFS at the farm level, with a system of two simultaneous equations representing the probability to adopt a contract, and the minimum farm-level payment triggering this adoption. We assess the effect of direct payments, and use the estimates to simulate a change of budget allocation from direct payments to environmental incentives. The ex-ante evaluation method proposed is developed with panel data from the French farm accountancy data network (FADN), and can be reproduced for other EU countries. A difficulty lies in overcoming missing information on the eligibility of farmers to AECM and/or OFS with a large set of control variables. We identify two effects of the budget transfer mechanism. The direct effect is a bigger budget available for meeting the supply of environmental commitments by more farmers and financing the adoption of more measures. The indirect effects of the

reduction of direct payments on farmers' behaviour are heterogeneous according to the farm type. In our transfer simulations, constrained by the current regulation (maximum 15% of direct payments), indirect effects are of limited extent and suggest that cutting into direct payments would not affect much the profitability of adopting environment-friendly practices. It calls for the implementation of complementary measures aiming at improving the environmental effectiveness of the public provision of public goods. Given the lower public budget allocated to the CAP for the 2023-2027 period, there is a need to rethink the design of positive incentives for environmentally sound agricultural practices and seek other contributors to complement taxpayers. In addition, contrary to the current AECM designed mainly through a supply-side approach, more efficient PES should better integrate the demand of ES.

In the third and fourth chapters, I study more specifically the design of payment mechanisms dedicated to ES. Based on the example of two specific PES, a hypothetical one and a real-life case study, I show how cost-effectiveness can be enhanced by adapting the targeting of conditionality rules to the environmental and technical problems addressed by the scheme.

In the third chapter, I focus on the delivery of public goods with threshold effects, such as biodiversity and water quality. The technical difficulty is to design a PES resulting in sufficient ES in a specific area to meet this ecological threshold. While the literature emphasizes that promoting landscape approaches, hence encouraging farmers from the same area to work together, is necessary, the small amount of initiatives shows that implementation is difficult, in particular because farmers' acceptance of collective requirements in PES is low. To overcome this issue, bonus mechanisms are an opportunity to introduce incentives for collective action as top-ups of payment conditioned to individual commitments. Using a survey-based approach, we test ex-ante the acceptability of a sponsorship bonus delivered to participants who enroll new farmers from the eligible area, combined or not with a collective result bonus delivered to all participants for meeting an environmental target defined at the landscape scale. The bonus options are included as an attribute in a choice experiment for a hypothetical PES contract for improving surface water quality in catchment areas in the northwest of France. The choice experiment approach measures and breaks down preferences for specific attributes of PES design, in particular for the bonus option. In addition, we propose individual per-hectare payment levels that can exceed those currently proposed in AECM to measure the farmers' willingness to accept which may go beyond income foregone. By doing so, we open the possibility for the hypothetical PES to be (partly) financed by (local) private or public contributors with a willingness to pay for water quality improvements (water catchment bodies,

local companies...). Results suggest that a sponsorship bonus by itself is cost-effective. However, its acceptability is lower when combined with a collective result bonus. We also show that preferences for conditional bonuses are heterogeneous and characterise this heterogeneity. In particular, this study suggests that introducing a bonus rewarding individual effort to convince new farmers to adopt the scheme is promising to promote landscape approaches, while collective bonuses distributed equally to all might be counterproductive as long as the payment for individual commitments is not high enough.

The fourth chapter aims at studying the design of cost-effective result-based PES for the provision of a linear global public good depending on aggregate efforts, such as climate change mitigation. Result-based PES pay individual farmers proportionally to the emissions mitigated, letting them choose the most efficient mitigation practices for their farming system. Technical difficulties arise on how to precisely capture and measure farmers' individual efforts to the provision of the public good, and to define the level of incentive for encouraging high aggregated mitigation efforts from the farming population. Inspired by a French case study, we study two design elements of PES targeting the reduction of enteric methane emissions on dairy farms which are crucial for their effectiveness: the choice of emissions indicator and the payment level. Using publicly available farm-level panel data from the French FADN, we compare enteric emissions computed with an IPCC Tier 2 method to baseline emissions from a Tier 3 method accounting for diet effects. We use the dual theory of production economics and estimate variable cost functions for different French dairy systems to quantify the extra-costs of milk production for reducing enteric emissions with more grasslands in fodder systems. Results stress the relevance of using an indicator sensitive to diet when defining economic incentives to precisely measure farmers' effort for reducing enteric emissions. We also show that dairy systems are heterogeneous when it comes to the extra-costs they face for changing practices. Most farms exhibit significant and high additional costs, in particular plain farms with a large share of grasslands and mountain farms. To support a large-scale transition, the payment level should be sufficiently high to exceed those costs, or modulated according to the dairy system.

Throughout my PhD, I manipulated different types of data. Secondary data is useful to conduct analyses representative of the farming population when it comes to the modelling of PES adoption behaviour (chapter 2) and extra-costs (chapter 4). Collecting primary data in chapter 3 allows to measure farmers preferences for a hypothetical PES with the possibility of getting

rid of current budget constraints. We could introduce attributes that are not observed in current data and make ex-ante contributions.

In the modelling approaches, I represented PES considering different scales: the aggregate policy scale in chapter 2, the contract scale in chapter 3 and the payment design scale in chapter 4. This multi-scale approach allows to get a broader picture on the different factors of PES environmental effectiveness and their limits, each one providing insights into the incentive signal sent to farmers. At the policy scale, the effectiveness of PES can be improved by better targeting the budget available (contributions from taxpayers) towards instruments for the provision of public goods. At the scale of the PES design, introducing new payment conditionality mechanisms such as collective and/or result-based incentives adapted to the public good targeted should boost the achievement of environmental results, on the condition that they are accepted and largely adopted by farmers. Hence, the improvement of PES design goes hand in hand with ensuring the payment level exceeds the willingness to accept of farmers. Allowing for contributions from a diversity of contributors with a willingness to accept can help raising enough budget. The three empirical approaches also contribute to characterise the heterogeneity of farming systems: profitability of adoption environment-friendly practices (chapter 2), acceptability of contract attributes (chapter 3), and extra-costs for changing practices (chapter 4).

The empirical analyses from chapter 2 to 4 focus on the behaviour of farmers facing economic incentives to supply ES. The empirical observations illustrate that current schemes are not paid enough to finance ES provision, and highlight the limitation of PES effectiveness from the lack of sufficient contributions to trigger large-scale adoption. It becomes necessary to also look at the demand side.

This observation led to pose the theoretical problem of how to increase the willingness to pay for ES in the fifth chapter. I focus on consumers, as they are the last stage of the food supply chain and as such, can send a price signal for the agricultural and food sector along all the value chain. Since the empirical literature suggests consumers care about their health when buying environment-friendly food products, we develop a theoretical model to show that health concerns can efficiently finance ES provision. The theoretical model proposes to capture additional contributions from consumers, and in particular, if there are private benefits to consume food products produced in an environment-friendly way. On the supply side, we consider the special case of an agri-environmental production technology that jointly provides

an ES and a food commodity with superior health benefits in comparison with a conventional agricultural technology. On the demand side, consumers have a choice between the food commodity produced with the conventional agricultural practices or with the environment-friendly practices. Expanding the impure public good model, we consider three market settings. One in which the consumers are provided with incomplete information that the “green” product jointly provides an environmental public good (environmental label), one in which they are provided with the incomplete information that it provides private health benefits (health label), and one in which they are provided with the full information (health and environment label). We consider homogeneous consumers and derive the market equilibria of the three market settings. Results show a health label leads to higher public good provisioning than an environmental label in most cases, with full information leading to the highest provision. Moreover, while there is underprovision of the public good in the sense of Pareto in all market settings, health labelling can lead to the optimal provisioning of the public good sought by an environmental agency (efficient market) if consumers’ preferences for health are high enough relative to their preferences for the environment. While PES initiatives from the private sector favours inefficiency problems from free riding of voluntary contributors, our theoretical results show that attaching private benefits to the funding of ES can temperate it. When it is possible to identify private benefits to the provision of ES, value chain included PES can be efficient instruments to complement agri-environmental policies. Investigations to understand the scope and diversity of joint production technologies might be fruitful to identify key private benefits valuable for consumers.

6.2. Main limits

The first type of limitations to the generalisation of the findings are that they rely on assumptions we had to make to overcome missing information from the available data.

Empirical results of chapter 2 and 4 are derived from the FADN, which contains little information to precisely characterise agricultural practices and environmental services implemented at the farm level. Linking the adoption of a PES to changes of agricultural practices and to environmental outcomes required making assumptions. The European Commission initiative and roadmap for the conversion of the FADN to the Farm Sustainability

Data Network (FSDN) will facilitate modelling of farmers' change of practices in the future (EC, 2022a).

In chapter 2, we estimate a farm-level acceptable payment using a large set of control variables describing the farm system and its size, to overcome the lack of information on the type of environmental commitments, payment amount per hectare and surfaces enrolled of participating farms. Yet, the inter-individual heterogeneity of participating farms and AECM measures is very high, and our current model fails to capture enough of it to reproduce accurately the observed behaviour. In particular, it tends to underestimate AECM adoption probabilities. It affects the robustness of the results and the quality of the simulations.

In chapter 4, to overcome the absence of data on the composition of dairy cows ration and on farm GHG emissions, an increase of the use of omega-3 rich feed in the diet of dairy cows is approximated by an increase of agricultural area dedicated to grass fodder production to evaluate the extra variable costs. Hence, we only characterise farms extra-costs heterogeneity for this specific lever. Information on grasslands yields would be necessary to evaluate extra-costs of more grass fodders more precisely. Moreover, Eco-Methane participants also add feed complements to increase sources of omega-3 in cows ration (such as linseed). Due to the absence of information on their purchase, we could not take this lever into account.

A limitation to the generalisation of the findings of chapter 3 is the biased sample collected to conduct the choice experiment, which is not representative of the farming systems of the regions targeted. This is mainly due to the sampling procedure which could not be randomized to follow the general data protection regulation. As a result, the sample is biased towards the population already the most likely to be willing to enroll in a PES and already implementing ambitious environmental services (such as organic or highly educated farmers). We are likely underestimating the actual willingness to accept of farmers for adopting the hypothetical contract evaluated. Moreover, inherent to the survey-based methodology used, results on preferences for the bonus options are likely to change in another area, depending on the context.

In addition, there are further limitations due to the scope of the studies.

In chapter 4, we study an economic incentive to reduce enteric methane emissions by increasing grasslands area on dairy farms. Accounting for spillovers of more grass on other GHG emissions (or farmland biodiversity) would better capture the environmental impact of such a result-based PES. Moreover, the environmental effectiveness of PES for reducing GHG

emissions per unit of product depends on not increasing total emissions. Hence, complementary levers are needed to ensure that production levels and demand for livestock products do not increase. It calls for a change of EU consumers' diet towards more plant-based products.

In chapter 5, we build a theoretical framework based on an assumption of complementary provision of health and environmental benefits by environment-friendly practices. This case does not apply to all types of environment-friendly practices, some of which cannot be linked to quality and/or nutritional improvements of the food product. We also consider a linear relationship between health benefits and public good provision, and do not account for consumers' heterogeneity. Relaxing one of those assumptions would affect the extent of our findings. For instance, results are not applicable for the case of local public goods, as not all consumers would benefit from public good provision and exhibit a willingness to pay for it. We can however assume health labelling would even more outperform environmental labelling in the case of local public good provision, strengthening the scope of our result.

I remain with further questions I could not pursue do to a lack of time and means.

Regarding the voluntary adoption model in chapter 2, I see two possibilities to improve the robustness of the model and the simulations. First, the econometric approach could be developed, in particular by better capturing individual fixed effects with panel estimation, for instance by distinguishing the mean values over the 5 years analyzed and the difference to the mean on a yearly basis every year for all covariates potentially varying from one year to another. This would better capture the supply of environmental commitments. To better characterize the demand from public authorities, adding more information on the type of AECM adopted by FADN farms and eligible areas is feasible by matching with the dataset on the beneficiaries of the CAP second pillar payments. This would give us access to the type of AECM and the payment per hectare enrolled for this specific measure.

To identify the optimal level of incentive for adding more grass in dairy systems in chapter 4, I was constrained with the unavailability of representative data allowing to link enteric methane emissions to fodder rotation systems. Ideally, an interesting output would be to answer the question: for an announced price of tCO₂eq, how many dairy farmers would be willing to participate in a PES like Eco-Methane? The idea would have then been to link the extra-costs of changing practices (grass surfaces) to units of ES (reduction of enteric methane emissions in tCO₂eq). It could have been done by working together with the Bleu-Blanc-Coeur association

to collect new data on fodder rotation systems and diet composition using the yearly questionnaire among Eco-Methane participants. Since Bleu-Blanc-Coeur measures their enteric methane emissions every month, it would allow the estimation of emission reductions as a function of diet and fodder rotation system information. If robust enough, this ES supply function could be applied to estimate emissions reduction with FADN data, together with extra-costs.

Finally, the findings of the fifth chapter open up new questions on the characterization of complementary joint production of ES and quality/nutritional characteristics of food products. In particular, I am interested in exploring the case of producers of protected designation of origin products for which agricultural practices are constrained with rules on natural resources management. A hypothesis is that for some quality products tied to the implementation of more extensive practices, the joint complementary provision of ES might be facilitated. This complementarity could be empirically observed if producers of protected designation of origin products or located in an area eligible to the label tend to engage more in AECM.

Appendices

Appendix A1. Farm Accountancy Data Network sample coverage of farms with organic practices

Table A1.1. Sample coverage of farms with organic practices in 2019.

	In conversion to organic farming	Certified organic	Certified or in conversion to organic farming
France			
Number of farms	n.a	n.a	47,196
Share of farms (%)	n.a	n.a	10.4
UAA (ha)	565,574	1,675,711	2,241,345
Share of UAA (%)	1.9	5.8	8.3
Sample ¹			
Number of farms	5,905	24,805	30,710
Share of farms (%)	2.0	8.6	10.6
UAA (ha)	545,601	1,705,243	2,250,844
Share of UAA (%)	2.1	6.5	8.6

UAA: utilised agricultural area. ¹ Weighted by the extrapolation coefficient.

Sources: 2019 French FADN data, 2019 Agence Bio data.

Appendix A2. Descriptive statistics of the Farm Accountancy Data Network sample

Table A2.1. Education level of the farms of the sample.

Level of education	%
Agricultural	
None or training of less than 120 hours	6.85
Primary agricultural education	12.57
Secondary agricultural education (short)	41.27
Secondary agricultural education (long)	27.57
Agricultural higher education (short)	10.53
Agricultural higher education (long)	1.20
General	
None	7.14
Primary school certificate	11.82
Secondary education (short)	50.52
Secondary education (long)	26.30
Non-agricultural higher education	4.22

Source: 2016-2019 French FADN data.

Table A2.2. Regions of the farms of the sample.

Region	%
Ile de France	1.42
Champagne-Ardenne	6.23
Picardie	3.52
Haute-Normandie	2.20
Centre	5.97
Basse-Normandie	3.90
Bourgogne	4.99
Nord Pas de Calais	3.40
Lorraine	2.54
Alsace	2.25
Franche-Comté	1.98
Pays de la Loire	8.16
Bretagne	8.31
Poitou-Charentes	5.69
Aquitaine	7.62
Midi-Pyrénées	8.40
Limousin	2.55
Rhône-Alpes	6.66
Auvergne	4.59
Languedoc Roussillon	5.25
Provence-Alpes-Côte d'Azur	3.84
Corse	0.54

Source: 2016-2019 French FADN data.

Table A2.3. Technical orientations of the farms of the sample.

Technical orientation	OTEX number	%
Cereals, oleaginous, protein crops	15	18.25
Other field crops	16	6.70
Vegetable gardening	28	1.73
Horticulture	29	2.07
Wine with quality label	37	13.81
Other wine	38	1.50
Other permanent crops	39	2.46
Dairy farming	45	14.97
Beef farming	46	10.39
Mixed cattle farming	47	3.53
Sheep and goat farming	48	5.47
Pigs and poultry farming	50	5.48
Mixed crops farming	61	1.64
Mixed livestock dominated by grazing livestock	73	1.20
Mixed livestock dominated by granivores	74	1.35
Mixed farming: field crops and grazing livestock	83	7.36
Mixed farming: other combination of crops and livestock	84	2.10

Source: 2016-2019 French FADN data

Appendix A3. Coefficients of the generalised Tobit models

Table A3.1. Estimates of the generalised Tobit models for the uptake of agri-environment-climate measures and organic farming support.

	AECM		OFS	
	Participation decision (D_i^*)	Acceptable payment (P_{ai}) in 1,000€	Participation decision (D_i^*)	Acceptable payment (P_{ai}) in 1,000€
Intercept	-1.125*** (0.041)	2.907*** (0.388)	-3.439*** (0.064)	-11.588*** (0.680)
Decoupled payments (100€/ha)	0.001 (0.001)	0.042 ⁺ (0.023)	0.006*** (0.000)	0.157*** (0.018)
Coupled payment for suckler cows (1,000€)	0.006*** (0.001)	0.213*** (0.001)	-0.019*** (0.001)	0.038** (0.013)
Fuel price (€/l)	0.501*** (0.025)	1.880*** (0.218)	0.149*** (0.034)	-0.030 (0.287)
Land lease (100€/ha)	-0.002*** (0.000)	0.039*** (0.005)	-0.002*** (0.000)	-0.030*** (0.006)
Standard gross production (100,000€)	-0.082*** (0.002)	0.068*** (0.017)	-0.030*** (0.003)	0.193*** (0.023)
Labour (AWU/ha)	0.007*** (0.001)	0.192*** (0.021)	-0.435*** (0.023)	0.980*** (0.267)
Utilised agricultural area (100ha)	0.186*** (0.004)	2.493*** (0.037)	0.090*** (0.006)	8.247*** (0.062)
Depreciation (10,000€/ha)	-0.005*** (0.001)	-0.399*** (0.079)	-0.043 ⁺ (0.021)	-2.384*** (0.349)
Share of rented land	0.180*** (0.008)	-1.230*** (0.072)	0.020 ⁺ (0.010)	1.208*** (0.091)
Less favoured area	-0.021** (0.007)	-0.779*** (0.057)	0.121*** (0.011)	-0.080 (0.091)
Cereals, oleaginous, protein crops, other field crops	-0.487*** (0.009)	0.466*** (0.082)	0.021 (0.015)	1.315*** (0.137)
Vegetable gardening, horticulture	-1.153*** (0.026)	-0.396 (0.336)	0.238*** (0.022)	0.428* (0.187)
Wine with quality label, other wine	-0.457*** (0.013)	0.152 (0.138)	-0.055** (0.018)	0.976*** (0.159)
Other permanent crops	-0.534*** (0.021)	0.837*** (0.214)	0.777*** (0.020)	3.661*** (0.167)
Dairy farming	-0.103*** (0.009)	2.018*** (0.078)	0.351*** (0.016)	3.161*** (0.135)
Beef farming	0.047*** (0.010)	0.755*** (0.076)	0.261*** (0.018)	-1.521*** (0.149)
Mixed cattle farming	0.167*** (0.011)	1.404*** (0.091)	0.200*** (0.025)	-0.432 ⁺ (0.225)
Sheep and goat farming	0.159*** (0.011)	0.675*** (0.088)	0.084*** (0.018)	-0.378* (0.147)
Pigs and poultry farming, mixed livestock dominated by granivores	-0.311*** (0.013)	-0.326** (0.117)	0.260*** (0.019)	0.559** (0.170)

Mixed crops farming	-0.472*** (0.022)	1.287*** (0.252)	0.396*** (0.023)	3.110*** (0.188)
Mixed livestock dominated by grazing livestock	-0.315*** (0.020)	1.883*** (0.210)	0.483*** (0.029)	0.142 (0.234)
Mixed farming: field crops and grazing livestock, other combination of crops and livestock	Baseline			
Age (years)	-0.007*** (0.000)	0.064*** (0.002)	-0.018*** (0.000)	0.010** (0.003)
No general education	-0.350*** (0.013)	-0.790*** (0.107)	-0.515*** (0.018)	-0.721*** (0.166)
Primary school certificate	-0.476*** (0.013)	-1.222*** (0.114)	-0.503*** (0.018)	0.989*** (0.186)
Secondary education (short)	-0.320*** (0.010)	-1.828*** (0.089)	-0.319*** (0.014)	-0.062 (0.130)
Secondary education (long)	-0.279*** (0.010)	-1.496*** (0.087)	-0.259*** (0.014)	-0.697*** (0.131)
Non-agricultural higher education	Baseline			
No agricultural education or training ≤120 h	-0.223*** (0.019)	-3.305*** (0.158)	0.0358 (0.026)	4.136*** (0.238)
Primary agricultural education	-0.239*** (0.019)	-3.940*** (0.145)	-0.000 (0.025)	3.962*** (0.229)
Secondary agricultural education (short)	-0.265*** (0.017)	-2.974*** (0.134)	0.202*** (0.023)	2.581*** (0.206)
Secondary agricultural education (long)	-0.230*** (0.017)	-2.657*** (0.132)	-0.017 (0.023)	3.694*** (0.209)
Agricultural higher education (short)	-0.086*** (0.017)	-2.387*** (0.135)	0.092*** (0.024)	3.841*** (0.210)
Agricultural higher education (long)	Baseline			
Share of permanent grasslands	0.490*** (0.010)	2.149*** (0.088)	-0.373*** (0.016)	-2.382*** (0.128)
Density of grazing livestock (LU/ha)	-0.022*** (0.004)	-1.014*** (0.062)	-0.143*** (0.011)	0.542*** (0.101)
Natura	0.408*** (0.009)	0.542*** (0.064)	-0.031+ (0.016)	-2.602*** (0.139)
Organic certification	0.790*** (0.009)	0.853*** (0.068)	2.285*** (0.008)	0.905*** (0.168)
Ile de France	0.495*** (0.032)	2.264*** (0.326)	2.342*** (0.055)	16.683*** (0.580)
Champagne-Ardenne	0.046 (0.029)	-1.344*** (0.276)	1.505*** (0.058)	8.126 (0.600)
Picardie	0.400*** (0.029)	0.692* (0.283)	2.260*** (0.054)	7.822 (0.577)
Haute-Normandie	-0.145*** (0.031)	0.230 (0.299)	2.066*** (0.056)	5.321 (0.581)
Centre	-0.091** (0.029)	2.805*** (0.280)	2.063*** (0.052)	9.058*** (0.559)
Basse-Normandie	-0.528*** (0.029)	2.179*** (0.272)	2.015*** (0.052)	5.635*** (0.549)
Bourgogne	-0.283*** (0.028)	-0.191 (0.273)	2.610*** (0.051)	8.352*** (0.547)
Nord Pas de Calais	0.201*** (0.030)	-1.456*** (0.297)	2.148*** (0.054)	7.245*** (0.587)
Lorraine	0.002 (0.029)	1.133*** (0.277)	2.590*** (0.053)	14.228*** (0.559)
Alsace	-0.063+ (0.033)	-1.453*** (0.290)	2.424*** (0.054)	8.818*** (0.572)
Franche-Comté	-0.399*** (0.030)	-3.773*** (0.285)	2.202*** (0.054)	3.617*** (0.563)

Pays de la Loire	0.083** (0.028)	3.677*** (0.274)	2.515*** (0.051)	6.037*** (0.545)
Bretagne	0.609*** (0.028)	3.920*** (0.275)	1.799*** (0.052)	6.028*** (0.558)
Poitou-Charentes	0.395*** (0.028)	2.184*** (0.268)	2.236*** (0.051)	9.370*** (0.553)
Aquitaine	-0.212*** (0.028)	-2.064*** (0.281)	2.409*** (0.050)	7.543*** (0.541)
Midi-Pyrénées	-0.475*** (0.028)	-3.120*** (0.281)	2.223*** (0.049)	8.293*** (0.535)
Limousin	-0.372*** (0.030)	-1.991*** (0.289)	2.351*** (0.054)	6.647*** (0.568)
Rhône-Alpes	0.049+ (0.028)	-2.121*** (0.269)	2.449*** (0.050)	6.851*** (0.536)
Auvergne	-0.293*** (0.028)	-4.169*** (0.276)	2.286*** (0.052)	6.927*** (0.553)
Languedoc Roussillon	0.142*** (0.028)	0.128 (0.283)	2.091*** (0.050)	6.643*** (0.537)
Provence-Alpes-Côte d'Azur	0.454*** (0.028)	1.852*** (0.277)	1.681*** (0.051)	4.618*** (0.550)
Corse	Baseline			
Observed participation in AECM in 2015	2.488*** (0.007)			
Observed participation in OFS at t-1	-0.640*** (0.012)	-1.754*** (0.096)		
Observed participation in OFS in 2015			1.449*** (0.010)	
Observed participation in AECM at t-1			-0.354*** (0.013)	-0.916*** (0.114)
2016	-0.511*** (0.008)	-0.083 (0.063)	-0.270*** (0.010)	-0.770*** (0.091)
2017	-0.345*** (0.006)	-0.209*** (0.054)	-0.282*** (0.009)	-0.465*** (0.083)
2018	-0.242*** (0.006)	0.032 (0.050)	-349*** (0.009)	-0.550*** (0.079)
2019	Baseline			
ρ	-0.034*** (0.005)		0.229*** (0.011)	
σ		5.619*** (0.013)		7.102*** (0.021)
Number of observations	28,967		28,967	
Payment observations	2,442		1,657	
Log likelihood	-506,741		-321,181	
AIC	1,013,733		642,613	
Schwarz criterion	1,015,228		644,109	
Pseudo-R2 (McFadden)	0.237		0.516	

Significance levels: *** p-value <0.001, ** p-value <0.01, * p-value<0.05, + p-value<0.1. Standard errors in parentheses.

AWU : annual work unit. LU: livestock unit. AECM: Agri-Environment-Climate Measure. OFS: Organic farming support.

Source: own elaboration.

Appendix A4. Choice experiment survey

Contexte et objectif du jeu qui vous est proposé :

La pollution de la ressource en eau, en partie due à l'érosion et au lessivage des sols agricoles, est un problème environnemental et économique majeur. La présence de nitrates, de phosphates et de pesticides dans l'eau impacte considérablement la biodiversité notamment du fait des phénomènes d'eutrophisation. Pour préserver cette biodiversité et pour répondre à des impératifs de santé publique, d'importants coûts sont générés pour réaliser des opérations de dépollution et de traitement de l'eau et de restauration des milieux. Certaines pratiques peuvent prévenir ces risques comme l'implantation de haies et la couverture du sol, qui permettent de limiter l'érosion et les flux de polluants précédemment évoqués.

Afin d'encourager le développement de ces pratiques, des démarches de **Paiements pour Services Environnementaux** (PSE) sont étudiés. Il s'agit d'une rétribution versée par les bénéficiaires de ces services (acteurs publics ou privés des territoires) aux agriculteurs **volontaires** pour leurs actions permettant de maintenir ou d'améliorer les services rendus par les écosystèmes.

Cette enquête que nous proposons a pour but d'identifier les **préférences des agriculteurs** pour la mise en place d'un potentiel dispositif de PSE, afin de garantir **l'adhésion d'un maximum d'agriculteurs**. Nous supposons ici que le versement de ce PSE ne remet pas en question les autres paiements perçus, notamment dans le cadre de la PAC.

Pour cela, nous allons vous proposer plusieurs scénarii représentant des **contrats** qui pourraient être développés. Chaque contrat prend en compte **4 critères** : le linéaire de **haies multistrates multiessences**, le **taux de couverture du sol** moyen de la SAU, le **paiement individuel** reçu par les agriculteurs participant au contrat pour les services environnementaux rendus et, pour terminer, le **bonus collectif et le parrainage**. Les couverts végétaux et les haies permettent de limiter l'érosion des sols et donc les flux de polluants.

Règle du jeu :

Nous allons vous proposer plusieurs **ensembles de choix de contrats de PSE**. Ces sont totalement fictifs. Ils ont été créés spécifiquement pour le questionnaire. Il s'agit d'une **expérience** qui ne vous engage en aucun cas à adhérer à de tels contrats. Nous vous demandons toutefois de répondre **comme s'il s'agissait d'une proposition réelle**.

Pour chaque ensemble de choix, nous allons vous proposer 2 contrats de PSE. **Vous aurez le choix entre :**

1/ Accepter **le contrat de PSE A**

2/ Accepter **le contrat de PSE B**

3/ **Aucun des deux contrats/Conserver vos pratiques actuelles.**

L'adoption d'un contrat de PSE est totalement volontaire : vous avez le choix de refuser le PSE A et le PSE B si vous considérez que la rémunération est insuffisante ou que les obligations de gestion sont inatteignables.

Les haies :

ATTENTION ! Les haies basses, les taillis monospécifiques ou autres alignements d'arbres ne compteront pas dans le linéaire. En effet, les haies doivent être **multistrates** (arbres, arbustes, etc...) et **multiessences** (plusieurs espèces). Elles doivent être d'une largeur minimale de **2,50 m**. L'installation des haies est **à 100% subventionnée et réalisée** par d'autres organismes (Breizh Bocage par exemple). Seul l'entretien serait à votre charge, avec **1 entretien minimum tous les 5 ans**.

3 niveaux vous seront proposés dans les contrats fictifs de PSE, à savoir :

- **20 m** de linéaire de haies par hectare de SAU



- **60 m** de linéaire de haies par hectare de SAU



- **100 m** de linéaire de haies par hectare de SAU

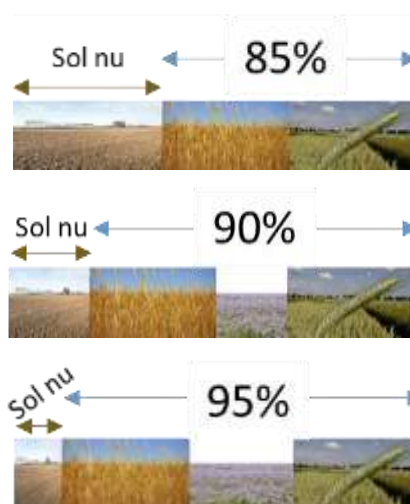


La couverture du sol :

La **couverture du sol** est déterminée selon le **nombre de jours par an** pendant lesquels vos terres ont un couvert végétal. Elle dépend de vos surfaces arables et de vos surfaces en prairies permanentes. (Cf. exemple de choix à la fin de ces explications)

3 niveaux vous seront proposés :

- Un taux de couverture du sol de **85%**
- Un taux de couverture du sol de **90%**
- Un taux de couverture du sol de **95%**



Le paiement individuel :

Il s'agit du paiement que vous recevrez pour la mise en place de pratiques limitant l'érosion.

4 niveaux vous seront proposés :

- Un paiement de **150€/ha de SAU** par an
- Un paiement de **300€/ha de SAU** par an
- Un paiement de **450€/ha de SAU** par an
- Un paiement de **600€/ha de SAU** par an



Le bonus parrainage :

Pour que le dispositif de PSE soit efficace, il faut qu'un maximum d'agriculteurs adhèrent au contrat. Il est proposé d'offrir une prime aux agriculteurs qui parrainent d'autres agriculteurs. L'objectif de ce bonus est d'inciter les agriculteurs à diffuser l'intérêt du PSE auprès des agriculteurs de leur territoire.

Le bonus parrainage est de **450 € par agriculteur parrainé**, en une seule fois et cumulable.



Le bonus collectif :




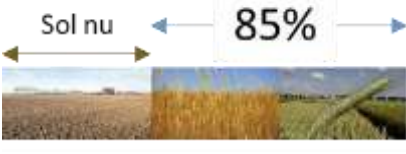




Un bonus collectif est proposé si, au terme de l'année civile, le **cours d'eau principal de votre bassin versant est classifié dans une catégorie de qualité supérieure**. La qualité de l'eau du cours d'eau est déterminée notamment par sa concentration en pesticides, nitrates et phosphates et par sa biodiversité.

Il s'agit d'un bonus collectif conditionné à l'amélioration de la qualité de l'eau. Il est payé tous les ans à partir du moment où l'objectif est atteint. Il est remis en cause dans le cas contraire.

L'amélioration de la qualité de l'eau permet de limiter les coûts de dépollution de l'eau et de restauration de la biodiversité. Ainsi, en cas d'attente de cet objectif, un bonus de **50€/ha/an** de SAU serait versé à tous les agriculteurs du territoire engagés dans le dispositif.



Exemple de choix :

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	 100 m/ha de SAU	 60 m/ha de SAU	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU	 95%	 85%	
Paiement individuel	450€/ha de SAU 	300€/ha de SAU 	
Parrainage et bonus collectif	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	Aucun	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	

Vous disposez ici de trois choix : choisir le contrat A, le contrat B ou conserver vos pratiques (« ne choisir aucun des deux contrats proposés » ?)

Exemple contrat A :

Vous avez 50 ha de SAU répartis en 25 ha de prairies permanentes et 25 ha de cultures arables.

1/ Il faudrait implanter $50 \times 100 = 5000$ m linéaire de haies

2/ 25 ha de votre SAU sont à 100% couverts (prairies permanentes). Pour arriver à un taux de couverture de 95% de la SAU totale, il faut que le taux de couverture sur les 25 ha de cultures arables soit de 90%, ce qui correspond à $365 \times 90\% = 328,5$ jours de sols couverts. Vous ne devez donc **pas avoir plus de 36 jours de sols nus** pour ces 25 ha de **cultures arables**.

Vous ne devrez **pas avoir plus de 36 jours** de sol **non couvert** sur les terres arables.

3/ Vous recevrez **22 500€/an** de paiement individuel. Si l'objectif de qualité de l'eau est atteint, vous recevrez **2 500€/an** supplémentaire.

Si vous convainquez un agriculteur de se joindre au programme, vous disposeriez de **450€** supplémentaire par agriculteur parrainé.

Exemple contrat B :

Si vous avez 50 ha de SAU dont 25 ha de prairies permanentes (couvertes à 100%) et 25 de cultures arables.

1/ Il faudrait implanter $50 \times 600 = 3000$ m linéaire de haies.

2/ 25 ha de votre SAU sont à 100% couverts. Pour arriver à un taux de couverture de 85% de la SAU totale, il faut que le taux de couverture sur les 25 ha de cultures arables soit de 70%, ce qui correspond à $365 \times 70\% = 255$ jours de sols couverts. Vous ne devez donc **pas avoir plus de 109 jours de sols nus** pour ces 25 ha de **cultures arables**.

3/ Vous recevrez **15 000€/an de paiement individuel**. Ce contrat ne propose ni bonus collectif en fonction du résultat, ni incitation au parrainage.



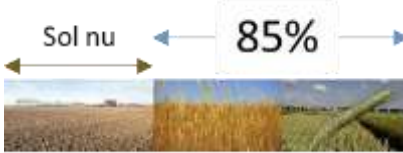





Questions préliminaires :

1. Quelle est la surface de votre SAU en prairies permanentes (en ha) ?
2. Quelle est la surface de votre SAU en cultures arables (en ha) ?
3. Quelle est la surface de votre SAU en culture permanente/verger (en ha) ?
4. Combien de jours vos sols arables sont-ils nus actuellement ?
5. Quel est le pourcentage d'enherbement de votre verger (correspond au pourcentage de couverture) ?
6. Quel linéaire total de haies (multi-strates et multi-essences) possédez-vous sur toute la SAU actuellement (en m)?



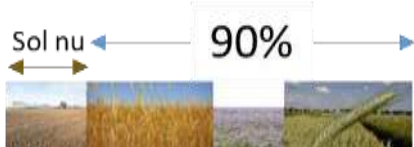
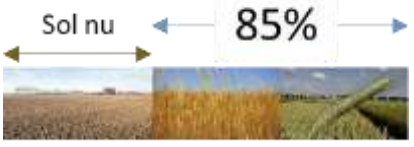






Suite à ces 6 questions, complétons le **calculateur EXCEL** et regardons quels seraient :

- La durée maximale pendant laquelle vos sols seraient nus
- Le linéaire de haies
- Votre rémunération supplémentaire



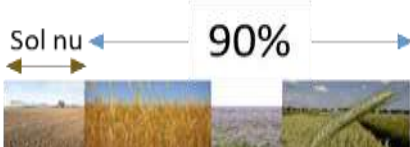
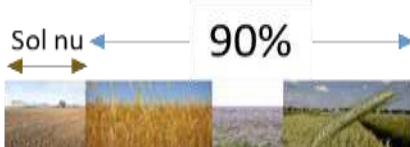



Questionnaire version 1, set 1 :

Attributs	Contrat A	Contrat B	Pas de contrat	
Haies	<p>100 m/ha de SAU</p> 	<p>60 m/ha de SAU</p> 	<p>Je préfère conserver mes pratiques actuelles</p>	
Taux de couverture moyen de la SAU				
Paiement individuel	 <p>150€/ha de SAU</p>	 <p>300€/ha de SAU</p>		
Parrainage et bonus collectif	<p>Aucun</p>	 <p>450€/agriculteur parrainé</p> <p>+</p> <p>Bonus collectif : 50€/ha de SAU</p> 		
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>



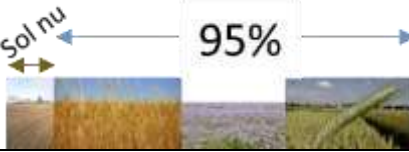
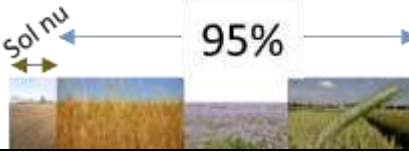





Questionnaire version 1, set 3 :

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	100 m/ha de SAU 	100 m/ha de SAU 	
Taux de couverture moyen de la SAU			
Paiement individuel	 600€/ha de SAU	 450€/ha de SAU	
Parrainage et bonus collectif	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	Je préfère conserver mes pratiques actuelles
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



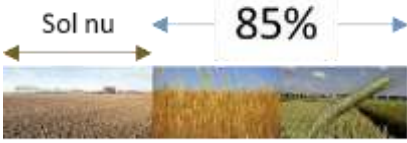





Questionnaire version 1, set 4 :

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	60 m/ha de SAU 	60 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	 450€/ha de SAU	 300€/ha de SAU	
Parrainage et bonus collectif	 450€/agriculteur parrainé	Aucun	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	








Questionnaire version 1, set 16 :

Attributs	Contrat A	Contrat B	Pas de contrat	
Haies	20 m/ha de SAU 	20 m/ha de SAU 		
Taux de couverture moyen de la SAU				
Paiement individuel	 300€/ha de SAU	 450€/ha de SAU	Je préfère conserver mes pratiques actuelles	
Parrainage et bonus collectif	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	 450€/agriculteur parrainé		
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>



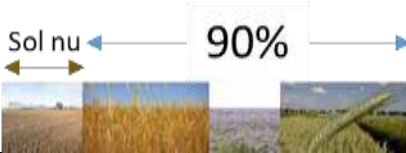




Questionnaire version 1, set 24 :

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	 <p>60 m/ha de SAU</p>	 <p>100 m/ha de SAU</p>	
Taux de couverture moyen de la SAU	 <p>85%</p>	 <p>95%</p>	
Paiement individuel	 <p>450€/ha de SAU</p>	 <p>150€/ha de SAU</p>	Je préfère conserver mes pratiques actuelles
Parrainage et bonus collectif	Aucun	 <p>450€/agriculteur parrainé</p> <p>+</p> <p>Bonus collectif : 50€/ha de SAU</p> 	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>




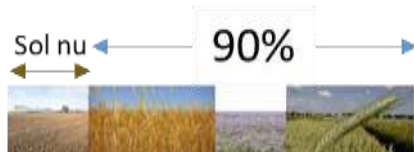



Questionnaire version 1, set 28 :

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	 <p>60 m/ha de SAU</p>	 <p>60 m/ha de SAU</p>	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU	 <p>95%</p>	 <p>85%</p>	
Paiement individuel	 <p>600€/ha de SAU</p>	 <p>450€/ha de SAU</p>	
Parrainage et bonus collectif	 <p>450€/agriculteur parrainé</p>	Aucun	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	




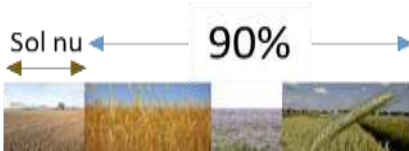



Questionnaire version 1, set 30 :

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	 <p>20 m/ha de SAU</p>	 <p>20 m/ha de SAU</p>	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU	 <p>90%</p>	 <p>95%</p>	
Paiement individuel	 <p>600€/ha de SAU</p>	 <p>150€/ha de SAU</p>	
Parrainage et bonus collectif	<p>450€/agriculteur parrainé</p> 	<p>Aucun</p>	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>








Questionnaire version 1, set 35 :

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	 <p>20 m/ha de SAU</p>	 <p>100 m/ha de SAU</p>	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU	 <p>95%</p>	 <p>90%</p>	
Paiement individuel	 <p>150€/ha de SAU</p>	 <p>600€/ha de SAU</p>	
Parrainage et bonus collectif	 <p>450€/agriculteur parrainé</p>	Aucun	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	



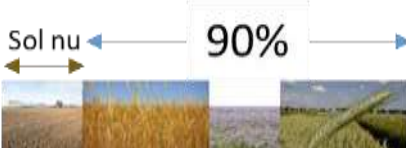






Questionnaire version 1, set 36 :

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	100 m/ha de SAU 	20 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	 300€/ha de SAU	 600€/ha de SAU	
Parrainage et bonus collectif	Aucun	450€/agriculteur parrainé 	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	




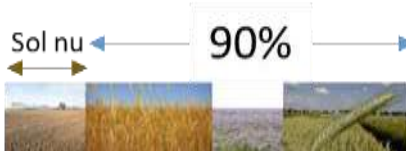




Questionnaire version 2, set 8:

Attributs	Contrat A	Contrat B	Pas de contrat	
Haies	20 m/ha de SAU 	100 m/ha de SAU 		
Taux de couverture moyen de la SAU			Je préfère conserver mes pratiques actuelles	
Paiement individuel	150€/ha de SAU 	150€/ha de SAU 		
Parrainage et bonus collectif	Aucun	 450€/agriculteur parrainé		
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	







Questionnaire version 2, set 9:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	 20 m/ha de SAU	 60 m/ha de SAU	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	 300€/ha de SAU	 600€/ha de SAU	
Parrainage et bonus collectif	450€/agriculteur parrainé 	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>









Questionnaire version 2, set 11:

Attributs	Contrat A	Contrat B	Pas de contrat	
Haies	100 m/ha de SAU 	60 m/ha de SAU 		
Taux de couverture moyen de la SAU			Je préfère conserver mes pratiques actuelles	
Paiement individuel	450€/ha de SAU 	150€/ha de SAU 		
Parrainage et bonus collectif	450€/agriculteur parrainé 	450€/agriculteur parrainé 		
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	



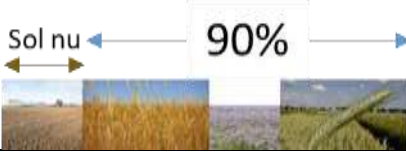
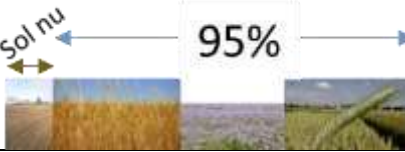






Questionnaire version 2, set 12:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	100 m/ha de SAU 	60 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	600€/ha de SAU 	300€/ha de SAU 	
Parrainage et bonus collectif	Aucun	Aucun	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



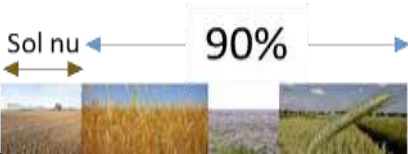
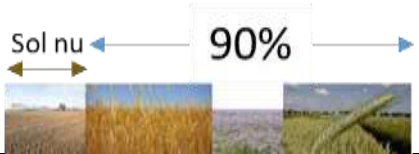




Questionnaire version 2, set 14:

Attributs	Contrat A	Contrat B	Pas de contrat	
Haies	100 m/ha de SAU 	20 m/ha de SAU 	Je préfère conserver mes pratiques actuelles	
Taux de couverture moyen de la SAU				
Paiement individuel	450€/ha de SAU 	450€/ha de SAU 		
Parrainage et bonus collectif	 450€/agriculteur parrainé	 450€/agriculteur parrainé		
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>









Questionnaire version 2, set 20:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	60 m/ha de SAU 	20 m/ha de SAU 	
Taux de couverture moyen de la SAU			
Paiement individuel	150€/ha de SAU 	150€/ha de SAU 	
Parrainage et bonus collectif	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	Je préfère conserver mes pratiques actuelles
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>




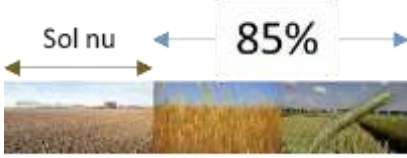




Questionnaire version 2, set 26:

Attributs	Contrat A	Contrat B	Pas de contrat	
Haies	60 m/ha de SAU 	100 m/ha de SAU 	Je préfère conserver mes pratiques actuelles	
Taux de couverture moyen de la SAU				
Paiement individuel	300€/ha de SAU 	450€/ha de SAU 		
Parrainage et bonus collectif	Aucun	450€/agriculteur parrainé  + Bonus collectif : 50€/ha de SAU 		
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>




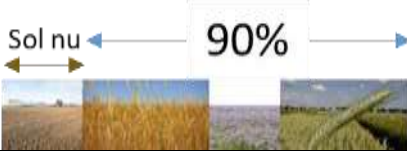




Questionnaire version 2, set 32:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	20 m/ha de SAU 	60 m/ha de SAU 	
Taux de couverture moyen de la SAU			
Paiement individuel	300€/ha de SAU 	300€/ha de SAU 	Je préfère conserver mes pratiques actuelles
Parrainage et bonus collectif	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	Aucun	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>




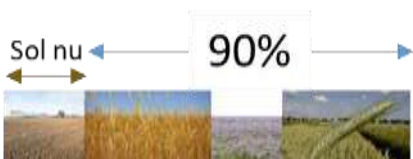





Questionnaire version 2, set 33:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	60 m/ha de SAU 	20 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paieement individuel	150€/ha de SAU 	600€/ha de SAU 	
Parrainage et bonus collectif	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	Aucun	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	




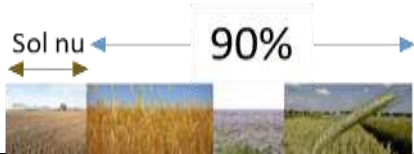





Questionnaire version 3, set 2:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	60 m/ha de SAU 	20 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	 600€/ha de SAU	 600€/ha de SAU	
Parrainage et bonus collectif	Aucun	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



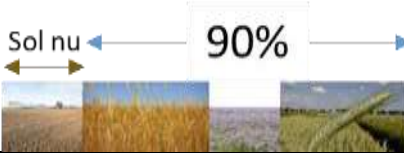






Questionnaire version 3, set 5:

Attributs	Contrat A	Contrat B	Pas de contrat	
Haies	20 m/ha de SAU 	60 m/ha de SAU 	Je préfère conserver mes pratiques actuelles	
Taux de couverture moyen de la SAU				
Paiement individuel	150€/ha de SAU 	 450€/ha de SAU		
Parrainage et bonus collectif	450€/agriculteur parrainé 	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 		
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	







Questionnaire version 3, set 15:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	<p>20 m/ha de SAU</p> 	<p>60 m/ha de SAU</p> 	
Taux de couverture moyen de la SAU			
Paiement individuel	 <p>600€/ha de SAU</p>	<p>150€/ha de SAU</p> 	Je préfère conserver mes pratiques actuelles
Parrainage et bonus collectif	<p>450€/agriculteur parrainé</p>  <p>+</p> <p>Bonus collectif : 50€/ha de SAU</p> 	 <p>450€/agriculteur parrainé</p>	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>









Questionnaire version 3, set 18:

Attributs	Contrat A	Contrat B	Pas de contrat	
Haies	 <p>60 m/ha de SAU</p>	<p>60 m/ha de SAU</p> 	Je préfère conserver mes pratiques actuelles	
Taux de couverture moyen de la SAU				
Paiement individuel	<p>450€/ha SAU</p>  <p>de</p>	 <p>600€/ha de SAU</p>		
Parrainage et bonus collectif	 <p>450€/agriculteur parrainé</p> <p>+</p> <p>Bonus collectif : 50€/ha de SAU</p> 	<p>450€/agriculteur parrainé</p> 		
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>



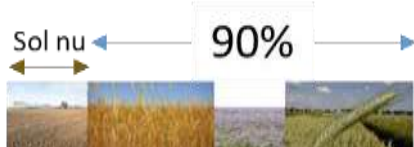





Questionnaire version 3, set 23:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	20 m/ha de SAU 	100 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	 450€/ha de SAU	450€/ha de SAU 	
Parrainage et bonus collectif	Aucun	Aucun	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	



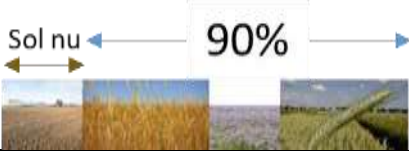
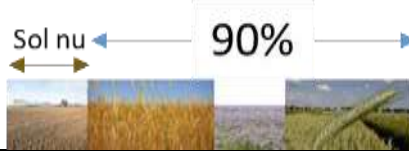


Questionnaire version 3, set 27:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	100 m/ha de SAU 	100 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	450€/ha de SAU 	600€/ha de SAU 	
Parrainage et bonus collectif	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	Aucun	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>




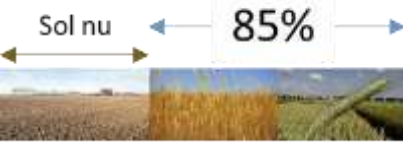



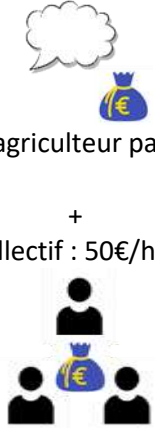
Questionnaire version 3, set 29:

Attributs	Contrat A	Contrat B	Pas de contrat	
Haies	100 m/ha de SAU 	100 m/ha de SAU 		
Taux de couverture moyen de la SAU			Je préfère conserver mes pratiques actuelles	
Paiement individuel	150€/ha de SAU 	300€/ha de SAU 		
Parrainage et bonus collectif	450€/agriculteur parrainé 	450€/agriculteur parrainé 		
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	



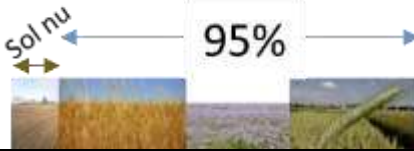







Questionnaire version 3, set 31:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	100 m/ha de SAU 	20 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	300€/ha de SAU 	150€/ha de SAU 	
Parrainage et bonus collectif	Aucun	Aucun	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	



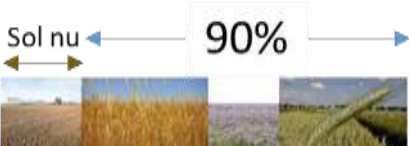
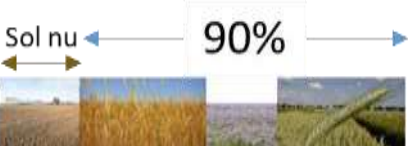




Questionnaire version 3, set 34:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	60 m/ha de SAU 	20 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	300€/ha de SAU 	300€/ha de SAU 	
Parrainage et bonus collectif	450€/agriculteur parrainé 	450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



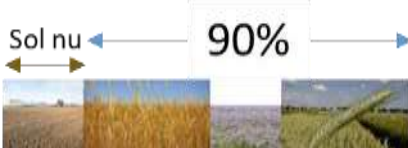



Questionnaire version 4, set 6:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	100 m/ha de SAU 	60 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	300€/ha de SAU 	150€/ha de SAU 	
Parrainage et bonus collectif	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	




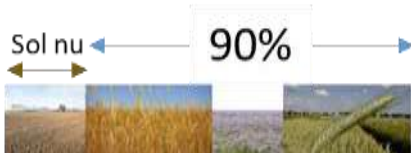





Questionnaire version 4, set 7:

Attributs	Contrat A	Contrat B	Pas de contrat	
Haies	 <p>100 m/ha de SAU</p>	<p>20 m/ha de SAU</p> 	Je préfère conserver mes pratiques actuelles	
Taux de couverture moyen de la SAU				
Paiement individuel	<p>150€/ha de SAU</p> 	 <p>450€/ha de SAU</p>		
Parrainage et bonus collectif	 <p>450€/agriculteur parrainé</p> <p>+</p> <p>Bonus collectif : 50€/ha de SAU</p> 	<p>Aucun</p>		
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>








Questionnaire version 4, set 10:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	20 m/ha de SAU 	60 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	450€/ha de SAU 	600€/ha de SAU 	
Parrainage et bonus collectif	Aucun	Aucun	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	








Questionnaire version 4, set 13:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	60 m/ha de SAU 	100 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	600€/ha de SAU 	300€/ha de SAU 	
Parrainage et bonus collectif	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	 450€/agriculteur parrainé	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	




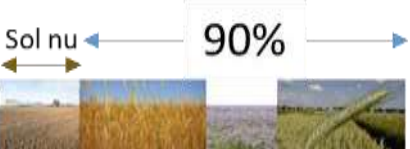






Questionnaire version 4, set 17:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	60 m/ha de SAU 	100 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	300€/ha de SAU 	150€/ha de SAU 	
Parrainage et bonus collectif	450€/agriculteur parrainé 	Aucun	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>










Questionnaire version 4, set 19:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	60 m/ha de SAU 	60 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	150€/ha de SAU 	450€/ha de SAU 	
Parrainage et bonus collectif	Aucun	 450€/agriculteur parrainé	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



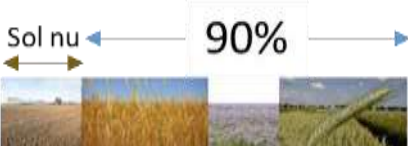




Questionnaire version 4, set 21:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	20 m/ha de SAU 	20 m/ha de SAU 	
Taux de couverture moyen de la SAU			
Paiement individuel	450€/ha de SAU 	300€/ha de SAU 	
Parrainage et bonus collectif	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	 450€/agriculteur parrainé + Bonus collectif : 50€/ha de SAU 	Je préfère conserver mes pratiques actuelles
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Questionnaire version 4, set 22:

Attributs	Contrat A	Contrat B	Pas de contrat	
Haies	<p>100 m/ha de SAU</p> 	<p>20 m/ha de SAU</p> 	<p>Je préfère conserver mes pratiques actuelles</p>	
Taux de couverture moyen de la SAU				
Paiement individuel	<p>600€/ha de SAU</p> 	<p>600€/ha de SAU</p> 		
Parrainage et bonus collectif	 <p>450€/agriculteur parrainé</p>	 <p>450€/agriculteur parrainé</p> <p>+</p> <p>Bonus collectif : 50€/ha de SAU</p> 		
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	

Questionnaire version 4, set 25:

Attributs	Contrat A	Contrat B	Pas de contrat
Haies	20 m/ha de SAU 	20 m/ha de SAU 	Je préfère conserver mes pratiques actuelles
Taux de couverture moyen de la SAU			
Paiement individuel	 600€/ha de SAU	 300€/ha de SAU	
Parrainage et bonus collectif	Aucun	450€/agriculteur parrainé 	
Je choisis :	<input type="checkbox"/>	<input type="checkbox"/>	

Appendix A5. Attribution of Eco-Methane scenarios to the French regions

Table A5.1 Eco-Methane scenarios attribution to the French regions

Administrative Region	Department	Scenarios	Production share in 2018 (volume)	Attributed scenarios
Ile de France		1, 3 or 5		1, 3 or 5
Champagne Ardennes		1, 3 or 5		1, 3 or 5
Picardie		1, 3 or 5		1, 3 or 5
Haute Normandie		1, 3 or 5		1, 3 or 5
Centre		1, 3 or 5		1, 3 or 5
Basse Normandie		2,4,6		2, 4 or 6
Bourgogne		1, 3 or 5		1, 3 or 5
Nord Pas De Calais		1, 3 or 5		1, 3 or 5
Lorraine	54	1,3 or 5	59%	1,3 or 5
	55	1,3 or 5		
	57	1,3 or 5		
	88	7 or 11		
Alsace		1, 3 or 5		1, 3 or 5
Franche-Comté	25	7 or 10	76%	7 or 10
	39	7 or 10		
	70	1, 3 or 5		
Pays de la Loire		2, 4 or 6		2, 4 or 6
Bretagne		1, 3 or 5		1, 3 or 5
Poitou-Charentes		1, 3 or 5		1, 3 or 5
Aquitaine		1, 3 or 5		1, 3 or 5
Midi-Pyrénées	46	7 or 8	60%	7 or 8
	12	7 or 8		
	9	1, 3 or 5	40%	
	31	1, 3 or 5		
	32	1, 3 or 5		
	65	1, 3 or 5		
	81	1, 3 or 5		
	82	1, 3 or 5		
Limousin		1, 3 or 5		
Rhône Alpes	1	1, 3 or 5	75%	1, 3 or 5
	7	1, 3 or 5		
	26	1, 3 or 5		
	38	1, 3 or 5		
	42	1, 3 or 5		
	69	1, 3 or 5		
	73	7 or 8	25%	
	74			

Auvergne		7 or 8		7 or 8
Languedoc-Roussillon	11	1, 3 or 5	10%	7 or 8
	30	1, 3 or 5		
	34	1, 3 or 5		
	66	1, 3 or 5		
	48	7 or 8	90%	
Provence Alpes Côte d'Azur	5	7 or 11	87%	7 or 11
	4	1, 3 or 5	13%	
	6	1, 3 or 5		
	13	1, 3 or 5		
	83	1, 3 or 5		
	84	1, 3 or 5		

Source: The authors, based on the French 2018 annual dairy survey and Bleu-Blanc-Coeur data.

Appendix A6. Instrumentation of grass fodder area and milk production in the estimation of milk production costs

Vector of instruments:

$$M_{it} = \begin{bmatrix} P_{1it} \\ P_{1it}^2 \\ Q_{1it} \\ Q_{1it}^2 \\ Q_{2it} \\ Q_{2it}^2 \\ Q_{3it} \\ Q_{3it}^2 \\ P_{1it}Q_{1it} \\ P_{1it}Q_{2it} \\ P_{1it}Q_{3it} \\ D_{1i} \\ \dots \\ D_{20i} \\ \ln Y_{2it} \\ \frac{\ln W_{2it}}{\ln W_{1it}} \\ \left(\frac{\ln W_{2it}}{\ln W_{1it}}\right)^2 \\ \ln Z_{2it} \\ \ln Z_{2it}^2 \\ \ln Z_{3it} \\ \ln Z_{3it}^2 \\ \ln Z_{2it} \ln Z_{3it} \\ \ln \frac{W_{2it}}{W_{1it}} \ln Z_{2it} \\ \ln \frac{W_{2it}}{W_{1it}} \ln Z_{3it} \end{bmatrix}$$

Appendix A7. Estimates of milk production cost and input cost share functions of French dairy systems

Table A7.1. Result of the system estimation for France (N=2,205)

Variable	Fuel cost share		Feed cost share		Variable cost	
	Parameter	P-value	Parameter	P-value	Parameter	P-value
$\ln Y_1$	-0.010**	0.002	0.010**	0.002	4.302***	0.000
$\ln \frac{W_2}{W_1}$	-0.008	0.120	0.008	0.120	0.484***	0.000
$\ln Z_1$	-0.008***	0.000	0.008***	0.000	-0.099	0.881
$\ln Z_2$	0.001	0.578	-0.001	0.578	0.379 ⁺	0.095
$\ln Z_3$	0.001	0.669	-0.001	0.669	-4.039**	0.003
$\ln Y_1^2$					-0.704***	0.001
$\ln Y_1 \ln Z_1$					0.041	0.724
$\ln Y_1 \ln Z_2$					0.006	0.915
$\ln Y_1 \ln Z_3$					0.765**	0.001
$\ln Y_1 \ln \frac{W_2}{W_1}$					0.010**	0.002
$(\ln \frac{W_2}{W_1})^2$					0.004	0.120
$\ln Z_1 \ln \frac{W_2}{W_1}$					0.008***	0.000
$\ln Z_2 \ln \frac{W_2}{W_1}$					-0.001	0.578
$\ln Z_3 \ln \frac{W_2}{W_1}$					-0.001	0.669
$\ln Z_1^2$					0.303***	0.000
$\ln Z_1 \ln Z_2$					-0.212***	0.000
$\ln Z_1 \ln Z_3$					-0.156	0.304
$\ln Z_2^2$					0.067**	0.001
$\ln Z_2 \ln Z_3$					0.080	0.137
$\ln Z_3^2$					-0.479 ⁺	0.067
$\ln Y_2$					0.043***	0.000
Constant	0.516***	0.000	0.484***	0.000	-5.881 ⁺	0.054
Observations	2,205					
R^2	-306.452		-14.437		0.805	

⁺ p < 0.10, * p < 0.05, ** p < 0.01, *** p < 0.001

Source: own elaboration, based on French 2016-2018 FADN data.

Table A7.2. Result of the system estimation for the plains of the western region (N=645)

Variable	Fuel cost share		Feed cost share		Variable cost	
	Parameter	P-value	Parameter	P-value	Parameter	P-value
$\ln Y_1$	-0.033***	0.000	0.033***	0.000	-5.275	0.442
$\ln \frac{W_2}{W_1}$	-0.014 ⁺	0.082	0.014 ⁺	0.082	0.409***	0.000
$\ln Z_1$	0.022***	0.000	-0.022***	0.000	-3.672	0.127
$\ln Z_2$	0.002	0.438	-0.002	0.438	-2.539	0.232
$\ln Z_3$	-0.010 ⁺	0.064	0.010 ⁺	0.064	14.770 ⁺	0.088
$\ln Y_1^2$					0.036	0.979
$\ln Y_1 \ln Z_1$					0.742	0.152
$\ln Y_1 \ln Z_2$					0.734	0.164
$\ln Y_1 \ln Z_3$					-2.235	0.174
$\ln Y_1 \ln \frac{W_2}{W_1}$					0.033***	0.000
$(\ln \frac{W_2}{W_1})^2$					0.007 ⁺	0.082
$\ln Z_1 \ln \frac{W_2}{W_1}$					-0.022***	0.000
$\ln Z_2 \ln \frac{W_2}{W_1}$					-0.002	0.438
$\ln Z_3 \ln \frac{W_2}{W_1}$					0.010 ⁺	0.064
$\ln Z_1^2$					-0.080	0.834
$\ln Z_1 \ln Z_2$					0.125	0.624
$\ln Z_1 \ln Z_3$					-1.309 ⁺	0.051
$\ln Z_2^2$					-0.449 ⁺	0.074
$\ln Z_2 \ln Z_3$					0.313	0.415
$\ln Z_3^2$					2.929 ⁺	0.061
$\ln Y_2$					0.040*	0.044
Constant	0.591***	0.000	0.409***	0.000	32.432 ⁺	0.088
Observations	645					
R^2	-363.168		-18.822		0.430	

⁺ p < 0.10, * p < 0.05, ** p < 0.01, *** p < 0.001

Source: own elaboration, based on French 2016-2018 FADN data.

Table A7.3. Result of the system estimation for the plains outside the western region (N=975)

Variable	Fuel cost share		Feed cost share		Variable cost	
	Parameter	P-value	Parameter	P-value	Parameter	P-value
$\ln Y_1$	-0.025***	0.000	0.025***	0.000	1.830 ⁺	0.085
$\ln \frac{W_2}{W_1}$	-0.002	0.750	0.002	0.750	0.429***	0.000
$\ln Z_1$	-0.011***	0.000	0.011***	0.000	0.776	0.349
$\ln Z_2$	0.000	0.977	-0.000	0.977	0.641**	0.007
$\ln Z_3$	0.028***	0.000	-0.028***	0.000	-2.274	0.120
$\ln Y_1^2$					-0.127	0.519
$\ln Y_1 \ln Z_1$					-0.014	0.925
$\ln Y_1 \ln Z_2$					-0.075	0.228
$\ln Y_1 \ln Z_3$					0.090	0.700
$\ln Y_1 \ln \frac{W_2}{W_1}$					0.025***	0.000
$(\ln \frac{W_2}{W_1})^2$					0.001	0.750
$\ln Z_1 \ln \frac{W_2}{W_1}$					0.011***	0.000
$\ln Z_2 \ln \frac{W_2}{W_1}$					-0.000	0.977
$\ln Z_3 \ln \frac{W_2}{W_1}$					-0.028***	0.000
$\ln Z_1^2$					-0.046	0.529
$\ln Z_1 \ln Z_2$					-0.136*	0.024
$\ln Z_1 \ln Z_3$					0.297 ⁺	0.092
$\ln Z_2^2$					0.043 ⁺	0.084
$\ln Z_2 \ln Z_3$					0.189***	0.000
$\ln Z_3^2$					-0.351	0.204
$\ln Y_2$					0.045***	0.000
Constant	0.571***	0.000	0.429***	0.000	-1.125	0.753
Observations	975					
R^2	-276.247		-12.399		0.860	

⁺ p < 0.10, * p < 0.05, ** p < 0.01, *** p < 0.001

Source: own elaboration, based on French 2016-2018 FADN data.

Table A7.4. Result of the system estimation for the mountainous areas (N=585)

Variable	Fuel cost share		Feed cost share		Variable cost	
	Parameter	P-value	Parameter	P-value	Parameter	P-value
$\ln Y_1$	-0.010	0.138	0.010	0.138	0.131	0.940
$\ln \frac{W_2}{W_1}$	-0.012	0.257	0.012	0.257	0.467***	0.000
$\ln Z_1$	-0.021***	0.000	0.021***	0.000	-2.828	0.114
$\ln Z_2$	0.010***	0.000	-0.010***	0.000	2.295***	0.001
$\ln Z_3$	0.009	0.193	-0.009	0.193	3.166	0.142
$\ln Y_1^2$					0.451	0.363
$\ln Y_1 \ln Z_1$					0.524 ⁺	0.088
$\ln Y_1 \ln Z_2$					-0.650**	0.001
$\ln Y_1 \ln Z_3$					-0.634	0.107
$\ln Y_1 \ln \frac{W_2}{W_1}$					0.010	0.138
$(\ln \frac{W_2}{W_1})^2$					0.006	0.257
$\ln Z_1 \ln \frac{W_2}{W_1}$					0.021***	0.000
$\ln Z_2 \ln \frac{W_2}{W_1}$					-0.010***	0.000
$\ln Z_3 \ln \frac{W_2}{W_1}$					-0.009	0.193
$\ln Z_1^2$					-0.231	0.257
$\ln Z_1 \ln Z_2$					0.219 ⁺	0.063
$\ln Z_1 \ln Z_3$					-0.689	0.129
$\ln Z_2^2$					0.049	0.112
$\ln Z_2 \ln Z_3$					0.490***	0.000
$\ln Z_3^2$					1.082*	0.046
$\ln Y_2$					0.018*	0.024
Constant	0.533***	0.000	0.467***	0.000	4.394	0.322
Observations	585					
R^2	-289.395		-12.933		0.793	

⁺ p < 0.10, * p < 0.05, ** p < 0.01, *** p < 0.001

Source: own elaboration, based on French 2016-2018 FADN data.

Table A7.5. Result of the system estimation for plains with more than 30% of corn in the fodder area (N=767)

Variable	Fuel cost share		Feed cost share		Variable cost	
	Parameter	P-value	Parameter	P-value	Parameter	P-value
$\ln Y_1$	-0.038***	0.000	0.038***	0.000	-6.551*	0.039
$\ln \frac{W_2}{W_1}$	-0.005	0.518	0.005	0.518	0.421***	0.000
$\ln Z_1$	0.012**	0.009	-0.012**	0.009	2.191	0.414
$\ln Z_2$	0.005 ⁺	0.094	-0.005 ⁺	0.094	3.125**	0.003
$\ln Z_3$	0.004	0.534	-0.004	0.534	2.961	0.303
$\ln Y_1^2$					2.594***	0.001
$\ln Y_1 \ln Z_1$					-0.776	0.181
$\ln Y_1 \ln Z_2$					-1.017***	0.000
$\ln Y_1 \ln Z_3$					-1.007	0.138
$\ln Y_1 \ln \frac{W_2}{W_1}$					0.038***	0.000
$(\ln \frac{W_2}{W_1})^2$					0.002	0.518
$\ln Z_1 \ln \frac{W_2}{W_1}$					-0.012**	0.009
$\ln Z_2 \ln \frac{W_2}{W_1}$					-0.005 ⁺	0.094
$\ln Z_3 \ln \frac{W_2}{W_1}$					-0.004	0.534
$\ln Z_1^2$					0.255**	0.009
$\ln Z_1 \ln Z_2$					0.312 ⁺	0.060
$\ln Z_1 \ln Z_3$					0.427	0.353
$\ln Z_2^2$					0.351***	0.001
$\ln Z_2 \ln Z_3$					0.277	0.126
$\ln Z_3^2$					0.448	0.365
$\ln Y_2$					0.113***	0.000
Constant	0.579***	0.000	0.421***	0.000	13.227 ⁺	0.057
Observations	767					
R^2	-320.209		-17.680		0.754	

⁺ p < 0.10, * p < 0.05, ** p < 0.01, *** p < 0.001

Source: own elaboration, based on French 2016-2018 FADN data.

Table A7.6. Result of the system estimation for plains with less than 30% of corn in the fodder area (N=853)

Variable	Fuel cost share		Feed cost share		Variable cost	
	Parameter	P-value	Parameter	P-value	Parameter	P-value
$\ln Y_1$	-0.009 ⁺	0.086	0.009 ⁺	0.086	0.348	0.770
$\ln \frac{W_2}{W_1}$	-0.010	0.226	0.010	0.226	0.463 ^{***}	0.000
$\ln Z_1$	-0.007	0.102	0.007	0.102	-3.733 ^{***}	0.000
$\ln Z_2$	-0.002	0.263	0.002	0.263	0.699 [*]	0.016
$\ln Z_3$	-0.001	0.904	0.001	0.904	3.091 ⁺	0.050
$\ln Y_1^2$					-0.617 [*]	0.023
$\ln Y_1 \ln Z_1$					0.874 ^{***}	0.000
$\ln Y_1 \ln Z_2$					0.111	0.135
$\ln Y_1 \ln Z_3$					-0.370	0.170
$\ln Y_1 \ln \frac{W_2}{W_1}$					0.009 ⁺	0.086
$(\ln \frac{W_2}{W_1})^2$					0.005	0.226
$\ln Z_1 \ln \frac{W_2}{W_1}$					0.007	0.102
$\ln Z_2 \ln \frac{W_2}{W_1}$					0.002	0.263
$\ln Z_3 \ln \frac{W_2}{W_1}$					0.001	0.904
$\ln Z_1^2$					0.313 ⁺	0.078
$\ln Z_1 \ln Z_2$					-0.369 ^{***}	0.000
$\ln Z_1 \ln Z_3$					-0.732 ^{**}	0.002
$\ln Z_2^2$					-0.007	0.789
$\ln Z_2 \ln Z_3$					0.303 ^{***}	0.000
$\ln Z_3^2$					0.621 [*]	0.019
$\ln Y_2$					0.039 ^{***}	0.000
Constant	0.537 ^{***}	0.000	0.463 ^{***}	0.000	10.451 ^{**}	0.004
Observations	853					
R^2	-317.339		-13.522		0.759	

⁺ p < 0.10, ^{*} p < 0.05, ^{**} p < 0.01, ^{***} p < 0.001

Source: own elaboration, based on French 2016-2018 FADN data.

Appendix A8. Assumptions on the production technology of differentiated goods

We consider the producer uses a variable input z (fertilizer, pesticides) in quantity z_c to produce good c and in quantity z_g to produce good g according to the production technologies. We assume each technology follows a translated quadratic form, strictly concave in z (Carpentier and Letort, 2012; Femenia and Letort, 2016). The prices of these inputs are w_c and w_g , and we assume that $w_c < w_g$. The short-term producer's optimization program is written as follows:

$$\max_{z_c, z_g} \left\{ \Pi = p_c c + p_g g - w_c z_c - w_g z_g \mid c = \mu_c - 0.5 \frac{1}{\gamma_c} (\eta_c - z_c)^2, g = \mu_g - 0.5 \frac{1}{\gamma_g} (\eta_g - z_g)^2 \right\}. \quad (\text{A8.1})$$

Solving for the first-order condition, we obtained the demand for inputs and the supply of goods g and c at the producer's equilibrium:

$$z_c^* = \eta_c - \gamma_c \frac{w_c}{p_c}, z_g^* = \eta_g - \gamma_g \frac{w_g}{p_g} \quad (\text{A8.2})$$

$$g^* = \mu_g - 0.5 \gamma_g \left(\frac{w_g}{p_g} \right)^2, c^* = \mu_c - 0.5 \gamma_c \left(\frac{w_c}{p_c} \right)^2 \quad (\text{A8.3})$$

The choice of this form for the production technology allows us to have directly interpretable parameters. Parameters μ_c et μ_g represent the maximum production capacity of goods c and g ; parameters η_c et η_g represent the quantity of inputs required to achieve the maximum production of goods; and parameters γ_c et γ_g represent the impact of the price ratio on input uses and output supply. The two goods are characterized by different production technologies. To represent the fact that the production of good g is less polluting than the production of good c , we consider that $\mu_g = \mu_c$ and $\eta_g < \eta_c$, which means that less variable inputs that are considered polluting are needed to produce good g . We assume that $\gamma_c = \gamma_g = \gamma$. We also assume that the marginal cost of good g is higher than that of good c for a given level of production, such as:

$$\frac{w_g}{\eta_g - z_g} > \frac{w_c}{\eta_c - z_c} \quad (\text{A8.4})$$

Bibliography

- Abu Hatab, A., Bustamante, M., Clark, H., Havlík, P., House, J., Mbow, C., Ninan, K.N., Popp, A., Roe, S., Sohngen, B., Towprayoon, S., 2022. Agriculture, Forestry and Other Land Uses, in: *Climate Change 2022 : Mitigation of Climate Change*. pp. 1–30.
- Agence bio, 2022. Les chiffres clés. Key figures (in French). [WWW Document]. Agence bio: les chiffres clés. URL <https://www.agencebio.org/vos-outils/les-chiffres-cles/> (accessed 11.21.22).
- Agence bio, 2020. Les chiffres 2019 du secteur bio. 2019 organic sector figures (in French).
- Agence de l'eau Loire-Bretagne, 2020a. Vilaine et côtières bretons : d'est en ouest une situation contrastée. Vilaine and Breton coasts: from east to west a contrasting situation (in French) [WWW Document]. Agence de l'eau Loire-Bretagne. URL <https://agence.eau-loire-bretagne.fr/home/bassin-loire-bretagne/zoom-sur-la-qualite-des-eaux-en-loire-bretagne-2020.html?dossierCurrentElemente45c63ca-4536-4b29-97c5-1cc2713d5974=d567c88f-8d9b-4a41-93e0-2d66f45d7695> (accessed 11.4.22).
- Agence de l'eau Loire-Bretagne, 2020b. Maine-Loire-Océan, une situation très dégradée. Maine-Loire-Ocean, a very deteriorated situation (in French) [WWW Document]. Agence de l'eau Loire-Bretagne. URL <https://agence.eau-loire-bretagne.fr/home/bassin-loire-bretagne/zoom-sur-la-qualite-des-eaux-en-loire-bretagne-2020.html?dossierCurrentElemente45c63ca-4536-4b29-97c5-1cc2713d5974=044127e5-f646-4213-bda2-0c9f7a100af0> (accessed 11.4.22).
- Agence de l'eau Seine-Normandie, 2018. La qualité des rivières en Seine-Aval. The quality of rivers in Seine-Aval (in French).
- Agences de l'eau, 2022. Annexe au projet de loi de finances pour agences de l'eau. Annex to the Finance Bill for Water Agencies (in French).
- Agreste, 2022. Réseau d'information comptable agricole (RICA) - Exercice 2019. Farm accountancy data network - 2019 (in French) [WWW Document]. Sources, définitions, méthodes. URL <https://agreste.agriculture.gouv.fr/agreste-web/methodon/S-RICA-2019/methodon/> (accessed 11.9.22).
- Agreste, 2021. Réseau d'information comptable agricole : 2018-2020 (Régions hors-DOM). Farm accountancy data network : 2018-2020 (French Regions excluding overseas). [WWW Document]. Agreste - Réseau d'information comptable agricole (RICA). URL <https://agreste.agriculture.gouv.fr/agreste->

- web/disaron/RICA_REGION_SOC2013/detail/ (accessed 11.3.22).
- Agreste, 2019. Enquête annuelle laitière 2018. French 2018 annual dairy survey (in French). Agreste Chiffres et Données 13.
- Aldanondo-Ochoa, A.M., Almansa-Sáez, C., 2009. The private provision of public environment: consumer preferences for organic production systems. *Land Use Policy* 26, 669–682. <https://doi.org/10.1016/j.landusepol.2008.09.006>
- Allaire, G., Cahuzac, E., Simioni, M., 2011. Spatial diffusion and adoption determinants of European agri-environmental supports related to extensive grazing in France, in: 5èmes Journées de Recherches En Sciences Sociales. Dijon, p. 25.
- Allcott, H., Lockwood, B., Taubinsky, D., 2019. Regressive Sin Taxes, With an Application To the Optimal Soda Tax (No. 25841), NBER WORKING PAPER SERIES.
- Allen, B., Hart, K., Radley, G., Tucker, G., Keenleyside, C., Oppermann, R., Underwood, E., Menadue, H., Poux, X., Beaufoy, G., Herzon, I., Povellato, A., Vanni, F., Prazan, J., Hudson, T., Yellachich, N., 2014. Biodiversity protection through results based remuneration of ecological achievement. Report Prepared for the European Commission, DG Environment, Contract No ENV.B.2/ETU/2013/0046. Institute for European Environmental Policy, London.
- Alston, L.J., Andersson, K., Smith, S.M., 2013. Payment for Environmental Services: Hypotheses and Evidence (No. 18740), NBER WORKING PAPER SERIES.
- Altieri, M.A., 1995. *Agroecology: the Science of sustainable agriculture*, 2nd ed. Taylor & Francis.
- Alvarez, A., Arias, C., 2003. Diseconomies of size with fixed managerial ability. *American Journal of Agricultural Economics* 85, 134–142. <https://doi.org/10.1111/1467-8276.00108>
- Amemiya, T., 1984. Tobit models: A survey. *Journal of Econometrics* 24, 3–61. [https://doi.org/10.1016/0304-4076\(84\)90074-5](https://doi.org/10.1016/0304-4076(84)90074-5)
- Andreoli, M., Bartolini, F., Dupraz, P., Issanchou, A., Le Gloux, F., Olivieri, M., van Rosmalen, M., Schulp, N., Vergamini, D., 2022. Deliverable D4.1: Modelling land tenure and land dynamics in AECPGs provision. Reports on the role of land tenure and land dynamics in AECPGs provision. H2020 CONSOLE project.
- Bailly, M.-L., Delaunay, S., Issanchou, A., Leroux, C., Paillard, H., Thureau, B., 2022. Se lancer dans une démarche de PSE avec des collectifs d’agriculteurs: enseignements méthodologiques du projet LabPSE. Starting a PES approach with farmers’ collectives: methodological lessons from the LabPSE project (in French).
- Barghusen, R., Sattler, C., Deijl, L., Weebers, C., Matzdorf, B., 2021. Motivations of farmers

- to participate in collective agri-environmental schemes: the case of Dutch agricultural collectives. *Ecosystems and People* 17, 539–555. <https://doi.org/10.1080/26395916.2021.1979098>
- Bartkowski, B., Droste, N., Ließ, M., Sidemo-Holm, W., Weller, U., Brady, M. V., 2021. Payments by modelled results: A novel design for agri-environmental schemes. *Land Use Policy* 102. <https://doi.org/10.1016/j.landusepol.2020.105230>
- Batáry, P., Dicks, L. V, Kleijn, D., Sutherland, W.J., 2015. The role of agri-environment schemes in conservation and environmental management. *Conservation Biology* 29, 1006–1016. <https://doi.org/10.1111/cobi.12536>
- Ben-Othmen, M.A., Ostapchuk, M., 2019. Farmers’ preferences for grassland restoration: Evidence from France. 172nd EAAE Seminar ‘Agricultural policy for the environment or environmental policy for agriculture?’ May 28-29, 2019. Brussels.
- Besley, T., Ghatak, M., 2007. Retailing public goods: The economics of corporate social responsibility. *Journal of Public Economics* 91, 1645–1663. <https://doi.org/10.1016/j.jpubeco.2007.07.006>
- Bezner Kerr, R., Hasegawa, T., Lasco, R., Bhatt, I., Deryng, D., Farrell, A., Gurney-Smith, H., Ju, H., Lluch-Cota, S., Meza, F., Nelson, G., Neufeldt, H., Thornton, P., 2022. Food, Fibre and Other Ecosystem Products, in: Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegria, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., Rama, B. (Eds.), *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, USA, pp. 713–906. <https://doi.org/10.1017/9781009325844.007>
- Bleu-Blanc-Coeur, 2022a. Les partenaires engagés dans la démarche environnementale de Bleu-Blanc-Coeur. The partners involved in the Bleu-Blanc-Coeur environmental approach (in French) [WWW Document]. URL <https://bleu-blanc-coeur.org/a-propos/demarche-environnementale/les-partenaires-de-la-demarche-environnementale/> (accessed 11.21.22).
- Bleu-Blanc-Coeur, 2022b. Démarche environnementale : la démarche éco-méthane de Bleu-Blanc-Cœur. Environmental engagement: the Eco-Methane programme of Bleu-Blanc-Coeur (in French). [WWW Document]. URL <https://bleu-blanc-coeur.org/a-propos/demarche-environnementale/> (accessed 6.18.21).
- Bleu-Blanc-Coeur, 2020. Lait Bleu-Blanc-Coeur Pâturages à 0,79 € : quel retour au producteur? Bleu-Blanc-Coeur pasture milk at €0.79: what return to the producer?

- [WWW Document]. URL <https://bleu-blanc-coeur.org/actualites/economie-et-societe/lait-bleu-blanc-coeur-paturages-a-079-e-quel-retour-au-producteur/> (accessed 11.21.22).
- Boadi, D., Benchaar, C., Chiquette, J., Massé, D., 2004. Mitigation strategies to reduce enteric methane emissions from dairy cows: Update review. *Canadian Journal of Animal Science* 84, 319–335. <https://doi.org/10.4141/A03-109>
- Borreani, G., Coppa, M., Revello-Chion, A., Comino, L., Giaccone, D., Ferlay, A., Tabacco, E., 2013. Effect of different feeding strategies in intensive dairy farming systems on milk fatty acid profiles, and implications on feeding costs in Italy. *Journal of Dairy Science* 96, 6840–6855. <https://doi.org/10.3168/jds.2013-6710>
- Bottega, L., De Freitas, J., 2009. Public, private and nonprofit regulation for environmental quality. *Journal of Economics and Management Strategy* 18, 105–123. <https://doi.org/10.1111/j.1530-9134.2009.00209.x>
- Bougherara, D., Combris, P., 2009. Eco-labelled food products: What are consumers paying for? *European Review of Agricultural Economics* 36, 321–341. <https://doi.org/10.1093/erae/jbp023>
- Bougherara, D., Ducos, G., 2006. Farmers' preferences over conservation contract flexibility and duration : an estimation of the effect of transaction costs using choice experiment, in: 1ère Journée de l'ESNIE. Paris, pp. 1–26. <https://doi.org/hal-01939954>
- Bougherara, D., Lapiere, M., Préget, R., Sauquet, A., 2021. Do farmers prefer increasing, decreasing, or stable payments in Agri-environmental schemes? *Ecological Economics* 183. <https://doi.org/10.1016/j.ecolecon.2021.106946>
- Brécard, D., Hlaimi, B., Lucas, S., Perraudeau, Y., Salladarré, F., 2009. Determinants of demand for green products: an application to eco-label demand for fish in Europe. *Ecological Economics* 69, 115–125. <https://doi.org/10.1016/j.ecolecon.2009.07.017>
- Brécard, D., Lucas, S., Pichot, N., Salladarré, F., 2012. Consumer preferences for eco, health and fair trade labels. An application to seafood product in France. *Journal of Agricultural and Food Industrial Organization* 10, 1–30. <https://doi.org/10.1515/1542-0485.1360>
- Bruce, C., Laroia, A., 2007. The production of eco-labels. *Environmental and Resource Economics* 36, 275–293. <https://doi.org/10.1007/s10640-006-9028-9>
- Burel, F., Baudry, J., 1995. Social, aesthetic and ecological aspects of hedgerows in rural landscapes as a framework for greenways. *Landscape and Urban Planning* 33, 327–340. [https://doi.org/10.1016/0169-2046\(94\)02026-C](https://doi.org/10.1016/0169-2046(94)02026-C)
- Burton, R.J.F., Kuczera, C., Schwarz, G., 2008. Exploring farmers' cultural resistance to

- voluntary agri-environmental schemes. *Sociologia Ruralis* 48, 16–37.
<https://doi.org/10.1111/j.1467-9523.2008.00452.x>
- Burton, R.J.F., Schwarz, G., 2013. Result-oriented agri-environmental schemes in Europe and their potential for promoting behavioural change. *Land Use Policy* 30, 628–641.
<https://doi.org/10.1016/j.landusepol.2012.05.002>
- Cain, M., Lynch, J., Allen, M.R., Fuglestedt, J.S., Frame, D.J., Macey, A.H., 2019. Improved calculation of warming-equivalent emissions for short-lived climate pollutants. *npj Climate and Atmospheric Science* 29, 1–7. <https://doi.org/10.1038/s41612-019-0086-4>
- Carpentier, A., Letort, E., 2012. Accounting for Heterogeneity in Multicrop Micro-Econometric Models: Implications for Variable Input Demand Modeling. *American Journal of Agricultural Economics* 94, 209–224. <https://doi.org/10.1093/ajae/aar132>
- Caselli, F., Ventura, J., 2000. A Representative Consumer Theory of Distribution. *The American Economic Review* 90, 909–926.
- Casolani, N., Nissi, E., Giampaolo, A., Liberatore, L., 2021. Evaluating the effects of European support measures for Italian organic farms. *Land Use Policy* 102, 105225.
<https://doi.org/10.1016/j.landusepol.2020.105225>
- Caubel-Forget, V., Grimaldi, C., Rouault, F., 2001. Contrasted dynamics of nitrate and chloride in groundwater submitted to the influence of a hedge. *Comptes Rendus de l'Academie de Sciences - Serie Ila: Sciences de la Terre et des Planetes* 332, 107–113.
[https://doi.org/10.1016/S1251-8050\(00\)01505-6](https://doi.org/10.1016/S1251-8050(00)01505-6)
- Chambres d'Agriculture des Pays de La Loire et de Bretagne, 2017. Projet CARBOCAGE: Valorisez le carbone stocké par les haies sur vos territoires. CARBOCAGE Project: Valorise the carbon stored by hedges in your territories (in French).
- Chaplin, S.P., Mills, J., Chiswell, H., 2021. Developing payment-by-results approaches for agri-environment schemes: Experience from an arable trial in England. *Land Use Policy* 109, 105698. <https://doi.org/10.1016/j.landusepol.2021.105698>
- Chatellier, V., Detang-Dessendre, C., Dupraz, P., Guyomard, H., 2021. The sensitivity of the income of French farms to a reorientation of aid under the future post-2023 CAP (in French) (No. 21– 03), Working Paper SMART - LERECO.
- Chatzimichael, K., Genius, M., Tzouvelekas, V., 2014. Informational cascades and technology adoption: Evidence from Greek and German organic growers. *Food Policy* 49, 186–195.
<https://doi.org/10.1016/j.foodpol.2014.08.001>
- Chilliard, Y., Martin, C., Rouel, J., Doreau, M., 2009. Milk fatty acids in dairy cows fed whole crude linseed, extruded linseed, or linseed oil, and their relationship with methane output.

- Journal of Dairy Science 92, 5199–5211. <https://doi.org/10.3168/jds.2009-2375>
- Christensen, T., Pedersen, A.B., Nielsen, H.O., Mørkbak, M.R., Hasler, B., Denver, S., 2011. Determinants of farmers' willingness to participate in subsidy schemes for pesticide-free buffer zones-A choice experiment study. *Ecological Economics* 70, 1558–1564. <https://doi.org/10.1016/j.ecolecon.2011.03.021>
- Citepa, 2020a. Inventaire des émissions de polluants atmosphériques et de gaz à effet de serre en France - Format Secten. National inventory of GHG and air pollutant emissions in France (in French). Citepa, Paris.
- Citepa, 2020b. Organisation et méthodes des inventaires nationaux des émissions atmosphériques en France OMINEA - 17^{ème} édition. Inventory methodology report of GHG and air pollutant emissions in France - 17th edition (in French). Citepa, Paris.
- Clements, K.W., Si, J.W., 2018. Engel's law, diet diversity, and the quality of food consumption. *American Journal of Agricultural Economics* 100, 1–22. <https://doi.org/10.1093/ajae/aax053>
- CNIEL, 2015. Observatoire de l'alimentation des vaches laitières: description des 8 principaux systèmes d'élevage. Edition 2015-2018. Dairy cows' feed observatory: description of the 8 main farming systems. 2015-2018 edition (in French). CNIEL, Paris.
- Coase, R., 1960. The problem of the Social Costs. *The Journal of Law and Economics* 6, 203–207.
- Commission of the European Communities, 1996. COM(96)59: European Community Water Policy. Brussels.
- Cooper, T., Hart, K., Baldock, D., 2009. The Provision of Public Goods through Agriculture in the European Union. London.
- Cornes, R., Sandler, T., 1994. The comparative static properties of the impure public good model. *Journal of Public Economics* 54, 403–421. [https://doi.org/10.1016/0047-2727\(94\)90043-4](https://doi.org/10.1016/0047-2727(94)90043-4)
- Cornes, R., Sandler, T., 1986. *The Theory of Externalities, Public Goods and Club Goods*.
- Council of the EU, 2009. Council Regulation (EC) No 73/2009 establishing common rules for direct support schemes for farmers under the common agricultural policy and establishing certain support schemes for farmers. *Official Journal of the European Union* 30, 16–99.
- Council of the European Communities, 1992a. Council regulation (EEC) No 2078/92 on agricultural production methods compatible with the requirements of the protection of the environment and the maintenance of the countryside. *Official Journal of the European Communities* 215, 85–90.

- Council of the European Communities, 1992b. Council Directive 92/43/ECC on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Communities 206.
- Council of the European Communities, 1991. Council Directive concerning the protection of waters against pollution caused by nitrates from agricultural sources. Official Journal of the European Communities 375, 1–8.
- Council of the European Communities, 1986. Council Directive 86/278/EEC on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. Official Journal of the European Communities 181, 6–12.
- Council of the European Communities, 1979. Council Directive on the conservation of wild birds (79/409/EEC). Official Journal of the European Communities 103, 1–18.
- Cullen, P., Dupraz, P., Moran, J., Murphy, P., O’Flaherty, R., O’Donoghue, C., O’Shea, R., Ryan, M., 2018. Agri-Environment Scheme Design: Past Lessons and Future Suggestions. *EuroChoices* 17, 26–30. <https://doi.org/10.1111/1746-692X.12187>
- D’Alberto, R., Raggi, M., Viaggi, D., Hamunen, K., Tarvainen, O., Haltia, E., 2022. Deliverable D3.2: Farmers and stakeholders opinions on implementation of suggested contract solutions based on survey results. H2020 CONSOLE project.
- Dabbert, S., 2006. Measuring and Communicating the Environmental Benefits of Organic Food Production. *Plant Management Network*. <https://doi.org/10.1094/CM-2006-0921-13-RV>
- Damianos, D., Giannakopoulos, N., 2002. Farmers’ participation in agri-environmental schemes in Greece. *British Food Journal* 104, 261–273. <https://doi.org/10.1108/00070700210425705>
- Darnhofer, I., D’Amico, S., Fouilleux, E., 2019. A relational perspective on the dynamics of the organic sector in Austria, Italy, and France. *Journal of Rural Studies* 68, 200–212. <https://doi.org/10.1016/j.jrurstud.2018.12.002>
- Dasgupta, P., 2021. *The Economics of Biodiversity: the Dasgupta Review*. HM Treasury, London. <https://doi.org/10.2458/jpe.2289>
- DDT Ariège, 2020. Calendrier prévisionnel de paiement des aides de la PAC pour la campagne 2019 et bilan des paiements 2019. Provisional timetable for the payment of CAP support for the 2019 campaign and balance of payments for 2019.
- Defrancesco, E., Gatto, P., Mozzato, D., 2018. To leave or not to leave? Understanding determinants of farmers’ choices to remain in or abandon agri-environmental schemes. *Land Use Policy* 76, 460–470. <https://doi.org/10.1016/j.landusepol.2018.02.026>
- Defrancesco, E., Gatto, P., Runge, F., Trestini, S., 2008. Factors affecting farmers’ participation

- in agri-environmental measures: A northern Italian perspective. *Journal of Agricultural Economics* 59, 114–131. <https://doi.org/10.1111/j.1477-9552.2007.00134.x>
- Département d’Ille-et-Vilaine, 2022. Pour une gestion durable de l’eau et des milieux aquatiques. For a sustainable management of water and aquatic habitats (in French) [WWW Document]. Département d’Ille-et-Vilaine. URL <https://www.ille-et-vilaine.fr/eau> (accessed 11.4.22).
- Déprés, C., Grolleau, G., Mzoughi, N., 2008. Contracting for environmental property rights: The case of Vittel. *Economica* 75, 412–434. <https://doi.org/10.1111/j.1468-0335.2007.00620.x>
- Desjeux, Y., Dupraz, P., Thomas, A., 2011. Les biens publics en agriculture, une voie vers l’écologisation de la PAC. Public goods in agriculture, a way towards greening the CAP (in French), in: Colloque «Ecologisation Des Politiques Publiques et Des Pratiques Agricoles». Avignon, France, pp. 1–15.
- Dong, Y., Bae, H.D., McAllister, T.A., Mathison, G.W., Cheng, K.J., 1997. Lipid induced depression of methane production and digestibility in the artificial rumen system (RUSITEC). *Canadian Journal of Animal Science* 77, 269–278. <https://doi.org/10.4141/A96-078>
- DRAAF Bretagne, 2022. Fiche territoriale synthétique RA 2020 “Bretagne”. Summary regional sheet of the 2020 agricultural census “Brittany” (in French). [WWW Document]. Les fiches territoriales, spécial recensement agricole 2020 - La Bretagne et ses départements. URL https://draaf.bretagne.agriculture.gouv.fr/IMG/html/fts_ra2020_bretagne.html#annexes (accessed 11.3.22).
- DRAAF Normandie, 2022. Fiche territoriale synthétique RA 2020 “Normandie”. Summary regional sheet of the 2020 agricultural census “Normandy” (in French). [WWW Document]. Chiffres clés des recensements agricoles par territoire. URL https://draaf.normandie.agriculture.gouv.fr/IMG/html/20220725-fts_ra2020_normandie.html (accessed 11.3.22).
- DRAAF Pays de la Loire, 2021. Recensement agricole 2020: Les Pays de la Loire, une région diversifiée majoritairement tournée vers l’élevage. Agricultural census 2020: Pays de Loire, a diversified region dominated by livestock farming (in French). *Agreste Etudes* 11, 1–4.
- Ducos, G., Dupraz, P., Bonnieux, F., 2009. Agri-environment contract adoption under fixed and variable compliance costs. *Journal of Environmental Planning and Management* 52,

- 669–687. <https://doi.org/10.1080/09640560902958248>
- Dupraz, P., 2021. Policies for the ecological transition of agriculture: the livestock issue. *Review of Agricultural, Food and Environmental Studies* 101, 529–538. <https://doi.org/10.1007/s41130-020-00135-7>
- Dupraz, P., Guyomard, H., 2019. Environment and climate in the common agricultural policy. *EuroChoices* 18, 18–25. <https://doi.org/10.1111/1746-692X.12219>
- Dupraz, P., Hamunen, K., Issanchou, A., Kurttila, M., Le Gloux, F., Raina, N., Viaggi, D., Viitala, E.-J., 2022. Deliverable D3.1: The participation of farmers in innovative contract solutions based on secondary data analyses. H2020 CONSOLE project.
- Dupraz, P., Latouche, K., Turpin, N., 2009. Threshold effect and co-ordination of agri-environmental efforts. *Journal of Environmental Planning and Management* 52, 613–630. <https://doi.org/10.1080/09640560902958164>
- Dupraz, P., Latouche, K., Turpin, N., 2007. Programmes agri-environnementaux en présence d’effets de seuils. *Cahiers d’économie et sociologie rurale* 82, 6–32.
- Dupraz, P., Pech, M., 2007. Effets des mesures agri-environnementales. *Effects of agri-environmental measures (in French)*. *INRA Sciences Sociales* 2, 1–4.
- Dupraz, P., Thareau, B., Coisson, T., Seyni, A.N., 2020. Conception of local carbon markets connecting farmers and companies : socio-economic outlines of innovative devices, in: 14th European IFSA Symposium Farming Systems: Facing Uncertainties and Enhancing Opportunities, International Farming Systems Association (IFSA). Evora, Portugal, pp. 1–13. <https://doi.org/10.25033/02503307>
- Durham, C.A., 2007. The Impact of Environmental and Health Motivations on the Organic Share of Produce Purchases. *Agricultural and Resource Economics Review* 2, 304–320. <https://doi.org/http://dx.doi.org/10.1017/S1068280500007115>
- Duval, L., Binet, T., Colle, A., Dupraz, P., Pech, M., 2019a. Favoriser le déploiement des paiements pour services environnementaux en agriculture: Guide à destination des collectivités territoriales. *Promoting payments for environmental services in agriculture: A guide for local authorities (in French)*.
- Duval, L., Binet, T., Colle, A., Martin, I., Dupraz, P., Pech, M., 2019b. Favoriser le déploiement des paiements pour services environnementaux en agriculture: Guide à destination des acteurs privés. *Promoting Payments for Environmental Services in agriculture: A guide for private actors (in French)*.
- Duval, L., Binet, T., Dupraz, P., Leplay, S., Etrillard, C., Pech, M., Deniel, E., Laustriat, M., 2016. Paiements pour services environnementaux et méthodes d’évaluation économique:

- enseignements pour les mesures agro-environnementales de la politique agricole commune (in French).
- EC, 2022a. Conversion to a Farm Sustainability Data Network (FSDN) [WWW Document]. Published initiatives. URL https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12951-Conversion-to-a-Farm-Sustainability-Data-Network-FSDN-_en (accessed 11.20.22).
- EC, 2022b. Knowledge base for the Sustainable Development Goals [WWW Document]. KnowSDGs Platform. URL <https://knowsdgs.jrc.ec.europa.eu/policies-sdgs> (accessed 8.24.22).
- EC, 2022c. COM(2022)304 Proposal for a regulation on nature restoration.
- EC, 2021a. COM(2021)400. Pathway to a Healthy Planet for All. EU Action Plan: Towards zero pollution for Air, Water and Soil. Brussels.
- EC, 2021b. Political agreement on new Common Agricultural Policy: fairer, greener, more flexible [Press release]. 2021, June 25. Brussels.
- EC, 2020a. A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system COM/2020/381 final. Brussels.
- EC, 2020b. EU Biodiversity Strategy for 2030 COM/2020/380 final. Brussels.
- EC, 2020c. Environment and Climate Action (Summary) [WWW Document]. Agridata - CAP Indicators. URL <https://agridata.ec.europa.eu/extensions/DashboardIndicators/Environment.html> (accessed 10.27.22).
- EC, 2020d. Organic Production [WWW Document]. Agridata - CAP Indicators. URL <https://agridata.ec.europa.eu/extensions/DashboardIndicators/OrganicProduction.html>
- EC, 2019. Definitive adoption 2019/333 of the European Union's general budget for the financial year 2019. Official Journal of the European Union L, 1–2350.
- EEA, 2022. Annual European Union greenhouse gas inventory 1990–2020 and inventory report 2022.
- EEA, 2021. Drivers of and pressures arising from selected key water management challenges. A European overview.
- EEA, 2020a. State of nature in the EU: Results from reporting under the nature directives 2013-2018.
- EEA, 2020b. Annual European Union greenhouse gas inventory 1990 – 2018 and inventory report 2020. Submission to the UNFCCC Secretariat. EEA, Copenhagen.
- EEA, 2019. EEA Signals 2019. Land and soil in Europe: Why we need to use these vital and

- finite resources sustainably. Copenhagen. <https://doi.org/10.2800/779710>
- Eichhorn, T., Kantelhardt, J., Schaller, L., Bartollini, F., Berzina, I., Bradfield, T., Cosgrove, M., Dupraz, P., Dzelzkaleja-Burmistre, M., Gatere, D., Haltia, E., Hamunen, K., Hennessy, T., Iglesias, A., Issanchou, A., Kurttila, M., Le Gloux, F., Leppänen, J., Majewski, E., Malak-Rawlikowska, A., Nikolov, D., Olivieri, M., Raggi, M., Runge, T., Schulp, N., Todorova, K., Tyllianakis, E., Blanco Velazquez, F.J., Vergamini, D., Viitala, E.-J., Viaggi, D., Zavalloni, M., 2022. Deliverable 2.6: Catalogue of updated factsheets of European in-depth case studies. H2020 CONSOLE project.
- Elliott, J., Image, M., 2018. Design of Agri-Environmental Schemes – evidence from the monitoring and evaluation GLAS in Ireland, in: 166th EAAE Seminar Sustainability in the Agri-Food Sector. Galway, p. 12.
- Ellis, J.L., Kebreab, E., Odongo, N.E., McBride, B.W., Okine, E.K., France, J., 2007. Prediction of methane production from dairy and beef cattle. *Journal of Dairy Science* 90, 3456–3466. <https://doi.org/10.3168/jds.2006-675>
- Engel, S., Pagiola, S., Wunder, S., 2008. Designing payments for environmental services in theory and practice: An overview of the issues. *Ecological Economics* 65, 663–674. <https://doi.org/10.1016/j.ecolecon.2008.03.011>
- Erickson, A., Kramer-Leblanc, C.S., 1997. Ecolabels: The Link Between Environmental Preferences and Green Practices?, in: *Strategy and Policy in the Food System: Emerging Issues*. pp. 195–206.
- Espinosa-Goded, M., Barreiro-Hurlé, J., Dupraz, P., 2013. Identifying additional barriers in the adoption of agri-environmental schemes: The role of fixed costs. *Land Use Policy* 31, 526–535. <https://doi.org/10.1016/j.landusepol.2012.08.016>
- EU, 2021. Regulation (EU) 2021/1119 establishing the framework for achieving climate neutrality (European Climate Law). *Official Journal of the European Union* 243, 1–17.
- EU, 2013a. Regulation (EU) No 1307/2013 establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy. *Official Journal of the European Union* 347, 608–670.
- EU, 2013b. Regulation (EU) No 1306/2013 on the financing, management and monitoring of the common agricultural policy. *Official Journal of the European Union* 347, 549–607.
- EU, 2013c. REGULATION (EU) No 1305/2013 on the financing, management and monitoring of the common agricultural policy. *Official Journal of the European Union* 347, 487–548.
- EU, 2010. Directive 2009/147/EC on the conservation of wild birds. *Official Journal of the European Union* 20, 7–25. <https://doi.org/10.1111/1467-9388.00079>

- EU, 2009. Directive 2009/128/EC establishing a framework for Community action to achieve the sustainable use of pesticides. *Official Journal of the European Union* 309, 71–86.
- EU, 2005. Council Regulation (EC) 1698/2005 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD). *Official Journal of the European Union* L, 1–40.
- EU, 2000. Directive 2000/60/EC establishing a framework for Community action in the field of water policy. *Official Journal of the European Communities* 327, 1–73.
- Eugène, M., Sauvant, D., Nozière, P., Viillard, D., Oueslati, K., Lherm, M., Mathias, E., Doreau, M., 2019. A new Tier 3 method to calculate methane emission inventory for ruminants. *Journal of Environmental Management* 231, 982–988. <https://doi.org/10.1016/j.jenvman.2018.10.086>
- European Court of Auditors, 2021. Common Agricultural Policy (CAP) and climate: half of EU climate spending but farm emissions are not decreasing. Special report No 16.
- European Court of Auditors, 2020. Biodiversity on farmland. Special report No 13.
- European Court of Auditors, 2017. Greening: a more complex income support scheme, not yet environmentally effective. Special report No 21.
- European Court of Auditors, 2011. Is agri-environment support well designed and managed? Special report No 7.
- Falconer, K., 2002. Developing Co-operative Approaches to Agri-environmental Policy, in: Hagedorn, K. (Ed.), *Environmental Cooperation and Institutional Change: Theories and Policies for European Agriculture*. Edward Elgar.
- FAO, 2007. La situation mondiale de l'alimentation et de l'agriculture: payer les agriculteurs pour les services environnementaux. *The State of Food and Agriculture: paying farmers for environmental service (in French)*.
- FAO, UNDP, UNEP, 2021. A Multi-Billion-Dollar Opportunity: repurposing agricultural support to transform food systems. Rome. <https://doi.org/https://doi.org/10.4060/cb6562en>
- Femenia, F., Letort, E., 2016. How to significantly reduce pesticide use: An empirical evaluation of the impacts of pesticide taxation associated with a change in cropping practice. *Ecological Economics* 125, 27–37. <https://doi.org/10.1016/j.ecolecon.2016.02.007>
- Florax, R.J.G.M., Travisi, C.M., Nijkamp, P., 2005. A meta-analysis of the willingness to pay for reductions in pesticide risk exposure. *European Review of Agricultural Economics* 32, 441–467. <https://doi.org/10.1093/erae/jbi025>

- Franks, J.R., 2019. An assessment of the landscape-scale dimensions of land based environmental management schemes offered to farmers in England. *Land Use Policy* 83, 147–159. <https://doi.org/10.1016/j.landusepol.2019.01.044>
- Franks, J.R., 2011. The collective provision of environmental goods: A discussion of contractual issues. *Journal of Environmental Planning and Management* 54, 637–660. <https://doi.org/10.1080/09640568.2010.526380>
- Fuentes, M.C., Calsamiglia, S., Sánchez, C., González, A., Newbold, J.R., Santos, J.E.P., Rodríguez-Alcalá, L.M., Fontecha, J., 2008. Effect of extruded linseed on productive and reproductive performance of lactating dairy cows. *Livestock Science* 113, 144–154. <https://doi.org/10.1016/j.livsci.2007.03.005>
- Gavrilova, O., Leip, A., Dong, H., Macdonald, J., Gomez, C., Amon, B., Barahona Rosales, R., Agustin, Del Prado, A., Lima, M., Oyhantcabal, W., Weerden, T., Widiawati, Y., Bannink, A., Beauchemin, K., Clark, H., Leytem, A., Kebreab, E., Ngwabie, N., Vellinga, T., 2019. Emissions from livestock and manure management, in: 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories.
- Giannakis, E., Efstratoglou, S., Psaltopoulos, D., 2014. Modelling the impacts of alternative CAP scenarios through a system dynamics approach. *Agricultural Economics Review* 15, 48–67. <https://doi.org/10.22004/ag.econ.253682>
- Giovanopoulou, E., Nastis, S.A., Papanagiotou, E., 2011. Modeling farmer participation in agri-environmental nitrate pollution reducing schemes. *Ecological Economics* 70, 2175–2180. <https://doi.org/10.1016/j.ecolecon.2011.06.022>
- Gollnow, S., Lundie, S., Moore, A.D., McLaren, J., van Buuren, N., Stahle, P., Christie, K., Thylmann, D., Rehl, T., 2014. Carbon footprint of milk production from dairy cows in Australia. *International Dairy Journal* 37, 31–38. <https://doi.org/10.1016/j.idairyj.2014.02.005>
- Gorman, W.M., 1980. A possible procedure for analysing quality differentials in the egg market. *The Review of Economic Studies* 47, 843–856. <https://doi.org/10.2307/2296916>
- Gosal, A., Kendall, H., Reed, M., Mitchell, G., Rodgers, C., Ziv, G., 2020. Exploring ecosystem markets for the delivery of public goods in the UK. <https://doi.org/10.5518/100/48>
- Govindasamy, R., Italia, J., 1999. Predicting willingness-to-pay a premium for organically grown fresh produce. *Journal of Food Distribution Research* 30, 44–53. <https://doi.org/10.22004/ag.econ.27385>
- Grainger, C., Beauchemin, K.A., 2011. Can enteric methane emissions from ruminants be lowered without lowering their production? *Animal Feed Science and Technology* 166–

- 167, 308–320. <https://doi.org/10.1016/j.anifeedsci.2011.04.021>
- Greene, W.H., Hensher, D.A., 2003. A latent class model for discrete choice analysis: Contrasts with mixed logit. *Transportation Research Part B* 37, 681–698. [https://doi.org/10.1016/S0191-2615\(02\)00046-2](https://doi.org/10.1016/S0191-2615(02)00046-2)
- Grethe, H., Arens-Azevedo, U., Balmann, A., Biesaslki, H., Birner, R., Bokelmann, W., Christen, O., Gauly, M., Knierim, U., Latacz-Lohmann, U., Martinez, J., Nieberg, H., Offermann, F., Pischetsrieder, M., Qaim, M., Renner, B., Schmid, J., Spiller, A., Taube, F., Voget-Kleschin, L., Weingarten, P., 2018. For an EU Common Agricultural Policy serving the public good after 2020: Fundamental questions and recommendations. *Berichte über Landwirtschaft* 1–85. <https://doi.org/https://doi.org/10.12767/buel.v0i225.220>
- Griffith, R., O’Connell, M., Smith, K., 2018. Corrective taxation and externalities from food consumption. *CESifo Economic Studies* 64, 1–14. <https://doi.org/10.1093/cesifo/ifx018>
- Grolleau, G., Caswell, J.A., 2006. Interaction between food attributes in markets: The case of environmental labeling. *Journal of Agricultural and Resource Economics* 31, 471–484. <https://doi.org/10.2139/ssrn.708483>
- Grolleau, G., Ibanez, L., Mzoughi, N., 2009. Too much of a good thing? Why altruism can harm the environment? *Ecological Economics* 68, 2145–2149. <https://doi.org/10.1016/j.ecolecon.2009.02.020>
- Grolleau, G., McCann, L.M.J., 2012. Designing watershed programs to pay farmers for water quality services: Case studies of Munich and New York City. *Ecological Economics* 76, 87–94. <https://doi.org/10.1016/j.ecolecon.2012.02.006>
- Gruau, G., Dupas, R., Le Goffe, P., Ropars-Collet, C., Weigand, C., Brient, L., Latouche, P., Moisan, S., Casquin, A., Gu, S., Le Moal, M., Houenou Hounsinou, M., Canlet, J., Poulain, M., 2019. Bilan des travaux préliminaires conduits sur le Bassin Versant du Lac au Duc en vue d’implanter des Paiements pour Services Environnementaux avec l’objectif de réduire les apports de phosphore d’origine agricole au lac (in French).
- Hagemann, M., Hemme, T., Ndambi, A., Alqaisi, O., Sultana, M.N., 2011. Benchmarking of greenhouse gas emissions of bovine milk production systems for 38 countries. *Animal Feed Science and Technology* 166–167, 46–58. <https://doi.org/10.1016/j.anifeedsci.2011.04.002>
- Hausman, J., McFadden, D., 1984. Specification Tests for the Multinomial Logit Model. *Econometrica* 52, 1219–1240.
- Havlík, P., Veysset, P., Boisson, J.M., Lherm, M., Jacquet, F., 2005. Joint production under

- uncertainty and multifunctionality of agriculture: Policy considerations and applied analysis. *European Review of Agricultural Economics* 32, 489–515. <https://doi.org/10.1093/erae/jbi027>
- Heal, G.M., Small, A.A., 2002. Agriculture and ecosystem services, in: Gardner, B., Rausser (Eds.), *Handbook of Agricultural Economics*. Elsevier B.V., p. 1341. [https://doi.org/10.1016/S1574-0072\(02\)10007-7](https://doi.org/10.1016/S1574-0072(02)10007-7)
- Heinz, I., 2008. Co-operative agreements and the EU Water Framework Directive in conjunction with the Common Agricultural Policy. *Hydrology and Earth System Sciences* 12, 715–726. <https://doi.org/10.5194/hess-12-715-2008>
- Herzon, I., Birge, T., Allen, B., Povellato, A., Vanni, F., Hart, K., Radley, G., Tucker, G., Keenleyside, C., Oppermann, R., Underwood, E., Poux, X., Beaufoy, G., Pražan, J., 2018. Time to look for evidence: Results-based approach to biodiversity conservation on farmland in Europe. *Land Use Policy* 71. <https://doi.org/10.1016/j.landusepol.2017.12.011>
- Hess, S., Palma, D., 2022. Apollo: a flexible, powerful and customisable freeware package for choice model estimation and application. Version 0.2.7. User manuel, www.apolloChoiceModelling.com. Leeds.
- Himics, M., Fellmann, T., Barreiro-Hurle, J., 2020. Setting Climate Action as the Priority for the Common Agricultural Policy: A Simulation Experiment. *Journal of Agricultural Economics* 71, 50–69. <https://doi.org/10.1111/1477-9552.12339>
- Hornick, S.B., 1992. Factors Affecting the Nutritional Quality of Crops. *American Journal of Alternative Agriculture* 7, 63–68. <https://doi.org/10.1111/j.1365-2621.1965.tb01797.x>
- Illes, A., Russi, D., Kettunen, M., Robertson, M., 2017. Innovative mechanisms for financing biodiversity conservation: experiences from Europe, final report in the context of the project "Innovative financing mechanisms for biodiversity in Mexico / N°2015/368378.
- INSEE, 2022. Exploitations agricoles selon la dimension économique. Agricultural holdings by economic size (in French) [WWW Document]. Chiffres-clés. URL <https://www.insee.fr/fr/statistiques/5358766#graphique-figure1> (accessed 2.15.22).
- IPBES, 2019. The global assessment report of the Intergovernmental Science-Policy platform on biodiversity and ecosystem services. IPBES secretariat, Bonn, Germany.
- Jaime, M.M., Coria, J., Liu, X., 2016. Interactions between CAP Agricultural and Agri-Environmental Subsidies and Their Effects on the Uptake of Organic Farming. *American Journal of Agricultural Economics* 98, 1114–1145. <https://doi.org/10.1093/ajae/aaw015>
- Jayasundara, S., Worden, D., Weersink, A., Wright, T., VanderZaag, A., Gordon, R., Wagner-

- Riddle, C., 2019. Improving farm profitability also reduces the carbon footprint of milk production in intensive dairy production systems. *Journal of Cleaner Production* 229, 1018–1028. <https://doi.org/10.1016/j.jclepro.2019.04.013>
- Kallas, Z., Serra, T., Gil, J.M., 2010. Farmers' objectives as determinants of organic farming adoption: The case of Catalonian vineyard production. *Agricultural Economics* 41, 409–423. <https://doi.org/10.1111/j.1574-0862.2010.00454.x>
- Karsenty, A., 2011. Payments for environmental services and development. Combining conservation incentives with investment. *Perspective-Cirad* 7, 4.
- Kebreab, E., Clark, K., Wagner-Riddle, C., France, J., 2006. Methane and nitrous oxide emissions from Canadian animal agriculture: A review. *Canadian Journal of Animal Science* 86, 135–158. <https://doi.org/10.4141/a05-010>
- Kerr, J.M., Vardhan, M., Jindal, R., 2014. Incentives, conditionality and collective action in payment for environmental services. *International Journal of the Commons* 8, 595–616. <https://doi.org/10.18352/ijc.438>
- Klimek, S., Richter gen. Kemmermann, A., Steinmann, H.H., Freese, J., Isselstein, J., 2008. Rewarding farmers for delivering vascular plant diversity in managed grasslands: A transdisciplinary case-study approach. *Biological Conservation* 141, 2888–2897. <https://doi.org/10.1016/j.biocon.2008.08.025>
- Koesling, M., Flaten, O., Lien, G., 2008. Factors influencing the conversion to organic farming in Norway. *International Journal of Agricultural Resources, Governance and Ecology* 7, 78–95. <https://doi.org/10.1504/ijarge.2008.016981>
- Kötchen, M.J., 2005. Impure public goods and the comparative statics of environmentally friendly consumption. *Journal of Environmental Economics and Management* 49, 281–300. <https://doi.org/10.1016/j.jeem.2004.05.003>
- Krämer, J.E., Wätzold, F., 2018. The agglomeration bonus in practice—An exploratory assessment of the Swiss network bonus. *Journal for Nature Conservation* 43, 126–135. <https://doi.org/10.1016/j.jnc.2018.03.002>
- Kuhfuss, L., Begg, G., Flanigan, S., Hawes, C., Piras, S., 2019. Should agri-environmental schemes aim at coordinating farmers' pro-environmental practices? A review of the literature, in: 172nd EAAE Seminar “Agricultural Policy for the Environment or Environmental Policy for Agriculture?” Brussels, pp. 1–36.
- Kuhfuss, L., Préget, R., Thoyer, S., Hanley, N., 2016. Nudging farmers to enrol land into agri-environmental schemes: The role of a collective bonus. *European Review of Agricultural Economics* 43, 609–636. <https://doi.org/10.1093/erae/jbv031>

- Lancaster, K.J., 1966. A new approach to consumer theory. *Journal of Political Economy* 74, 132–157. <https://doi.org/10.1086/259131>
- Landell-mills, N., Porras, I.T., 2002. Silver bullet or fool's gold? A global review of markets for forest environmental services and their impact on the poor. London. <https://doi.org/10.1038/240066c0>
- Läpple, D., Rensburg, T. Van, 2011. Adoption of organic farming: Are there differences between early and late adoption? *Ecological Economics* 70, 1406–1414. <https://doi.org/10.1016/j.ecolecon.2011.03.002>
- Latacz-Lohmann, U., Breustedt, G., 2019. Using choice experiments to improve the design of agri-environmental schemes. *European Review of Agricultural Economics* 46, 495–528. <https://doi.org/10.1093/erae/jbz020>
- Latacz-Lohmann, U., Schilizzi, S., 2005. Auctions for Conservation Contracts: A Review of the Theoretical and Empirical Literature, Report to the Scottish Executive Environment and Rural Affairs Department.
- Le Coent, P., Préget, R., Thoyer, S., 2017. Compensating Environmental Losses Versus Creating Environmental Gains: Implications for Biodiversity Offsets. *Ecological Economics* 142, 120–129. <https://doi.org/10.1016/j.ecolecon.2017.06.008>
- Le Gloux, F., Issanchou, A., Paillard, H., 2022. Quels contrats pour valoriser les services environnementaux des agriculteurs? Which contract types to value farmers' environmental services? (in French). *Travaux et Innovations* 289, 20–23.
- Le Gloux, F., Laporte, M., Duvaleix, S., Dupraz, P., 2021. Cost of changing dairy cows' diet to reduce enteric methane emissions in livestock farms (No. 21– 04), Working Paper SMART–LERECO. Rennes.
- Lefebvre, M., Espinosa, M., Gomez y Paloma, S., Paracchini, M.L., Piorr, A., Zasada, I., 2015. Agricultural landscapes as multi-scale public good and the role of the Common Agricultural Policy. *Journal of Environmental Planning and Management* 58, 2088–2112. <https://doi.org/10.1080/09640568.2014.891975>
- Lengers, B., Britz, W., Holm-Müller, K., 2013. Comparison of GHG-Emission indicators for dairy farms with respect to induced abatement costs, accuracy, and feasibility. *Applied Economic Perspectives and Policy* 35, 451–475. <https://doi.org/10.1093/aep/ppt013>
- Lichtenberg, E., 2002. Agriculture and the Environment, in: Gardner, B., Rausser, G. (Eds.), *Handbook of Agricultural Economics*. Elsevier B.V., pp. 1249–1313.
- Lorenz, H., Reinsch, T., Hess, S., Taube, F., 2019. Is low-input dairy farming more climate friendly? A meta-analysis of the carbon footprints of different production systems. *Journal*

- of Cleaner Production 211, 161–170. <https://doi.org/10.1016/j.jclepro.2018.11.113>
- Louviere, J., Hensher, D., Swait, J., 2000. Stated Choice Methods: Analysis and Applications. Cambridge University Press, Cambridge.
- Lusk, J.L., Nilsson, T., Foster, K., 2007. Public preferences and private choices: effect of altruism and free riding on demand for environmentally certified pork. *Environmental and Resource Economics* 36, 499–521. <https://doi.org/10.1007/s10640-006-9039-6>
- MAA, 2021a. La politique agricole commune 2015-2020 - Annexe 10 : Les mesures agro-environnementales et climatiques. The Common Agricultural Policy 2015-2020 - Annex 10: Agri-environmental and climate measures (in French).
- MAA, 2021b. Construire une politique agricole commune au service de l'agriculture française. Building a common agricultural policy to serve French agriculture (in French).
- MAA, 2020. Instruction technique relative aux Mesures AgroEnvironnementales et Climatiques et aux aides en faveur de l'agriculture biologique de la période 2015-2020 (in French).
- Mack, G., Ritzel, C., Jan, P., 2020. Determinants for the Implementation of Action-, Result- and Multi-Actor-Oriented Agri-Environment Schemes in Switzerland. *Ecological Economics* 176, 106715. <https://doi.org/10.1016/j.ecolecon.2020.106715>
- Madureira, L., Santos, J.L., Ferreira, A., Guimarães, H., 2013. Feasibility Study on the Valuation of Public Goods and Externalities in EU Agriculture, European Commission - JCR Scientific and Policy Reports. <https://doi.org/10.2791/22366>
- Magnusson, M.K., Arvola, A., Hursti, U.K.K., Åberg, L., Sjöden, P.O., 2003. Choice of organic foods is related to perceived consequences for human health and to environmentally friendly behaviour. *Appetite* 40, 109–117. [https://doi.org/10.1016/S0195-6663\(03\)00002-3](https://doi.org/10.1016/S0195-6663(03)00002-3)
- Mariel, P., Hoyos, D., Meyerhoff, J., Czajkowski, M., Dekker, T., Glenk, K., Bredahl Jacobsen, J., Liebe, U., Bøye Olsen, S., Sagebiel, J., Thiene, M., 2021. Environmental Valuation with Discrete Choice Experiments: Guidance on Design, Implementation and Data Analysis. SpringerBriefs in Economics. <https://doi.org/10.1007/978-3-030-62669-3>
- Markusen, J.R., 2013. Per-Capita Income As a Determinant of International Trade (No. 19754), NBER WORKING PAPER SERIES. Cambridge.
- Marmolo, E., 1999. A constitutional theory of public goods. *Journal of Economic Behavior and Organization* 38, 27–42. <https://doi.org/10.1007/BF02393262>
- Martin, C., Morgavi, D., Doreau, M., Jouany, J.P., 2006. Comment réduire la production de méthane chez les ruminants? How can the production of methane by ruminants be

- reduced ? (in French). *Fourrages* 187, 283–300.
- Martin, C., Morgavi, D.P., Doreau, M., 2010. Methane mitigation in ruminants: from microbe to the farm scale. *Animal* 4, 351–365. <https://doi.org/10.1017/S1751731109990620>
- Martin, C., Promiès, D., Ferlay, A., Rochette, Y., Martin, B., Chilliard, Y., Morgavi, D., Doreau, M., 2011. Methane output and rumen microbiota in dairy cows in response to long-term supplementation with linseed or rapeseed of grass silage or pasture based diets., in: *Proceedings of the New Zealand Society of Animal Production*, Volume 71. New Zealand Society of Animal Production, Invercargill, pp. 243–247.
- Martin, C., Rouel, J., Jouany, J.P., Doreau, M., Chilliard, Y., 2008. Methane output and diet digestibility in response to feeding dairy cows crude linseed, extruded linseed, or linseed oil. *Journal of Animal Science* 86, 2642–2650. <https://doi.org/10.2527/jas.2007-0774>
- MASA, 2022. Plan Stratégique National de la PAC 2023-2027 France : annexes et appendices. National Strategic Plan for the CAP 2023-2027 France: appendices (in French).
- Massfeller, A., Meraner, M., Hüttel, S., Uehleke, R., 2022. Farmers' acceptance of results-based agri-environmental schemes : A German perspective. *Land Use Policy* 120. <https://doi.org/10.1016/j.landusepol.2022.106281>
- Matthews, A., 2013. Greening agricultural payments in the EU's common agricultural policy. *Bio-based and Applied Economics* 2, 1–27. <https://doi.org/10.13128/BAE-12179>
- Matzdorf, B., Lorenz, J., 2010. How cost-effective are result-oriented agri-environmental measures?-An empirical analysis in Germany. *Land Use Policy* 27, 535–544. <https://doi.org/10.1016/j.landusepol.2009.07.011>
- McFadden, D., 1978. Cost, Revenue and Profit Functions, in: Fuss, M., McFadden, Daniel (Eds.), *Production Economics: A Dual Approach to Theory and Applications*, Volume I: The Theory of Production. North Holland, Amsterdam, pp. 2–109.
- McFadden, D., 1974. The measurement of urban travel demand. *Journal of Public Economics* 3, 303–328. [https://doi.org/10.1016/0047-2727\(74\)90003-6](https://doi.org/10.1016/0047-2727(74)90003-6)
- McGurk, E., Hynes, S., Thorne, F., 2020. Participation in agri-environmental schemes: A contingent valuation study of farmers in Ireland. *Journal of Environmental Management* 262, 110243. <https://doi.org/10.1016/j.jenvman.2020.110243>
- Merot, P., 1999. The influence of hedgerow systems on the hydrology of agricultural catchments in a temperate climate. *Agronomie* 19, 655–669. <https://doi.org/10.1051/agro:19990801>
- Millennium Ecosystem Assessment, 2005. Food and Ecosystems, in: *Ecosystems and Human Well-Being: Policy Responses*. Island Press, pp. 173–212.

- Mission Bocage, 2011. Retour d'expérience : mission Bocage. Feedback: Bocage mission (in French), in: *Captage Grenelle En Pays de La Loire: Réunion d'échange*. pp. 1–11.
- Molenaar, K., 2013. Payments for Ecosystem Services design characteristics.
- Moon, W., Florkowski, W.J., Brückner, B., Schonhof, I., 2002. Willingness to pay for environmental practices: implications for eco-labeling. *Land Economics* 78, 88–102. <https://doi.org/10.2307/3146925>
- Moschini, G., 1988. The Cost Structure of Ontario Dairy Farms: A Microeconomic Analysis. *Canadian Journal of Agricultural Economics* 36, 187–206. <https://doi.org/10.1111/j.1744-7976.1988.tb03271.x>
- Mosheim, R., Lovell, C.A.K., 2009. Scale economies and inefficiency of U.S. dairy farms. *American Journal of Agricultural Economics* 91, 777–794. <https://doi.org/10.1111/j.1467-8276.2009.01269.x>
- Mosnier, C., Britz, W., Julliere, T., De Cara, S., Jayet, P.A., Havlík, P., Frank, S., Mosnier, A., 2019. Greenhouse gas abatement strategies and costs in French dairy production. *Journal of Cleaner Production* 236, 1–11. <https://doi.org/10.1016/j.jclepro.2019.07.064>
- MTE, MASA, 2011. Arrêté relatif au programme d'actions national à mettre en oeuvre dans les zones vulnérables afin de réduire la pollution des eaux par les nitrates d'origine agricole. Decree on the national action programme to be implemented in vulnerable zones in order . Paris.
- Muradian, R., Corbera, E., Pascual, U., Kosoy, N., May, P.H., 2010. Reconciling theory and practice: An alternative conceptual framework for understanding payments for environmental services. *Ecological Economics* 69, 1202–1208. <https://doi.org/10.1016/j.ecolecon.2009.11.006>
- Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.-F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T., Zhang, H., 2013. Anthropogenic and natural radiative forcing, in: Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), *Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, New York, pp. 659–740. <https://doi.org/10.1017/CBO9781107415324.018>
- Negussie, E., de Haas, Y., Dehareng, F., Dewhurst, R.J., Dijkstra, J., Gengler, N., Morgavi, D.P., Soyeurt, H., van Gastelen, S., Yan, T., Biscarini, F., 2017. Invited review: Large-scale indirect measurements for enteric methane emissions in dairy cattle: A review of

- proxies and their potential for use in management and breeding decisions. *Journal of Dairy Science* 100, 2433–2453. <https://doi.org/10.3168/jds.2016-12030>
- Nehring, R., Gillespie, J., Sandretto, C., Hallahan, C., 2009. Small U.S. dairy farms: can they compete? *Agricultural Economics* 40, 817–825. <https://doi.org/10.1111/j.1574-0862.2009.00418.x>
- Njuki, E., Bravo-Ureta, B.E., 2015. The economic costs of environmental regulation in U.S. Dairy farming: a directional distance function approach. *American Journal of Agricultural Economics* 97, 1087–1106. <https://doi.org/10.1093/ajae/aav007>
- Njuki, E., Bravo-Ureta, B.E., Mukherjee, D., 2016. The good and the bad: environmental efficiency in northeastern U.S. dairy farming. *Agricultural and Resource Economics Review* 45, 22–43. <https://doi.org/10.1017/age.2016.1>
- OECD, 2003. Externalities. *Glossary of Statistical Terms*.
- OECD, 2001. Multifunctionality: towards an analytical framework. OECD. <https://doi.org/10.1787/9789264192171-en>
- Onozaka, Y., McFadden, D.T., 2011. Does local labeling complement or compete with other sustainable labels? A conjoint analysis of direct and joint values for fresh produce claims. *American Journal of Agricultural Economics* 93, 693–706. <https://doi.org/10.1093/ajae/aar005>
- Ostrom, E., 2002. Chapter 24 Common-pool resources and institutions: Toward a revised theory. *Handbook of Agricultural Economics* 2, 1315–1339. [https://doi.org/10.1016/S1574-0072\(02\)10006-5](https://doi.org/10.1016/S1574-0072(02)10006-5)
- Pagiola, S., Platais, G., 2002. Payments for Environmental Services. *Environment Strategy Notes* 3.
- Pavlis, E.S., Terkenli, T.S., Kristensen, S.B.P., Busck, A.G., Cosor, G.L., 2016. Patterns of agri-environmental scheme participation in Europe: Indicative trends from selected case studies. *Land Use Policy* 57, 800–812. <https://doi.org/10.1016/j.landusepol.2015.09.024>
- Pe'er, G., Bonn, A., Bruelheide, H., Dieker, P., Eisenhauer, N., Feindt, P.H., Hagedorn, G., Hansjürgens, B., Herzon, I., Lomba, Â., Marquard, E., Moreira, F., Nitsch, H., Oppermann, R., Perino, A., Röder, N., Schleyer, C., Schindler, S., Wolf, C., Zinngrebe, Y., Lakner, S., 2020. Action needed for the EU Common Agricultural Policy to address sustainability challenges. *People and Nature* 2, 305–316. <https://doi.org/10.1002/pan3.10080>
- Perrot-Maitre, D., 2006. *The Vittel payments for ecosystem services: a “perfect” PES case?* London.

- Poirier, J., Fleuret, A., 2015. Combien les résidents sont-ils disposés à payer pour des améliorations de la qualité de l'eau? How much are residents willing to pay for improving water quality? (in French). *Economie et Prévision* 206–207, 157–182. <https://doi.org/10.3917/ecop.206.0157>
- Prager, K., 2015. Agri-environmental collaboratives for landscape management in Europe. *Current Opinion in Environmental Sustainability* 12, 59–66. <https://doi.org/10.1016/j.cosust.2014.10.009>
- Prager, K., Reed, M., Scott, A., 2012. Encouraging collaboration for the provision of ecosystem services at a landscape scale-Rethinking agri-environmental payments. *Land Use Policy* 29, 244–249. <https://doi.org/10.1016/j.landusepol.2011.06.012>
- Pretty, J., 2003. Social Capital and the Collective Management of Resources. *Science* 302, 1912–1914. <https://doi.org/10.1126/science.1090847>
- Pufahl, A., Weiss, C.R., 2009. Evaluating the effects of farm programmes: Results from propensity score matching. *European Review of Agricultural Economics* 36, 79–101. <https://doi.org/10.1093/erae/jbp001>
- Puydarrieux, P., 2014. L'évaluation française des écosystèmes et des services d'écosystèmes (EFESE) (in French).
- Quillérou, E., Fraser, R., 2010. Adverse selection in the environmental stewardship scheme: Does the higher level stewardship scheme design reduce adverse selection? *Journal of Agricultural Economics* 61, 369–380. <https://doi.org/10.1111/j.1477-9552.2010.00240.x>
- Rogissart, L., Postic, S., Grimault, J., 2018. La Contribution Climat Energie en France : fonctionnement, revenus et exonérations. The Climate-Energy Contribution in France: operation, revenues and exemptions (in French). *Point Climat* 56, 1–7.
- Romstad, E., Vatn, A., Rørstad, P.K., Søyland, V., 2000. Multifunctional agriculture: implications for policy design. *Agricultural University of Norway, Department of Economics and Social Sciences* 21, 1–139.
- Rousseau, S., Vranken, L., 2013. Green market expansion by reducing information asymmetries: Evidence for labeled organic food products. *Food Policy* 40, 31–43. <https://doi.org/10.1016/j.foodpol.2013.01.006>
- Rudd, M.A., Pelletier, N., Tyedmers, P., 2011. Preferences for health and environmental attributes of farmed salmon amongst southern ontario salmon consumers. *Aquaculture Economics and Management* 15, 18–45. <https://doi.org/10.1080/13657305.2011.549405>
- Runge, T., Latacz-Lohmann, U., Schaller, L., Todorova, K., Daugbjerg, C., Termansen, M., Liira, J., Le Gloux, F., Dupraz, P., Leppanen, J., Fogarasi, J., Vigh, E.Z., Bradfield, T.,

- Hennessy, T., Targetti, S., Viaggi, D., Berzina, I., Schulp, C., Majewski, E., Bouriaud, L., Baciú, G., Pecurul, M., Prokofieva, I., Blanco Velazquez, F.J., 2022. Implementation of Eco-- schemes in Fifteen European Union Member States. *EuroChoices* 21, 19–27. <https://doi.org/10.1111/1746-692X.12352>
- Russi, D., Margue, H., Oppermann, R., Keenleyside, C., 2016. Result-based agri-environment measures: Market-based instruments, incentives or rewards? The case of Baden-Württemberg. *Land Use Policy* 54, 69–77. <https://doi.org/10.1016/j.landusepol.2016.01.012>
- Ruto, E., Garrod, G., 2009. Investigating farmers' preferences for the design of agri-environment schemes: a choice experiment approach. *Journal of Environmental Planning and Management* 52, 631–647. <https://doi.org/10.1080/09640560902958172>
- Samuelson, P.A., 1969. Contrast between Welfare Conditions for Joint Supply and for Public Goods. *The Review of Economics and Statistics* 51, 26–30.
- Samuelson, P.A., 1954. The Pure Theory of Public Expenditure. *The Review of Economics and Statistics* 36, 387–389.
- Sanders, J., Stolze, M., Padel, S., 2011. Use and efficiency of public support measures addressing organic farming. Braunschweig.
- Sandler, T., Tschirhart, J., 1997. Club Theory : Thirty Years Later. *Public Choice* 93, 335–355.
- Sauvant, D., Giger-Reverdin, S., Serment, A., Broudiscou, L., 2011. Influences des régimes et de leur fermentation dans le rumen sur la production de méthane par les ruminants (in French). *Productions Animales* 24, 433–446. <https://doi.org/10.20870/productions-animales.2011.24.5.3276>
- Schifferstein, H.N.J., Ophuist, P.A.M.O., 1998. Health-related determinants of organic food consumption in the Netherlands. *Food Quality and Preference* 9, 119–133. [https://doi.org/10.1016/S0950-3293\(97\)00044-X](https://doi.org/10.1016/S0950-3293(97)00044-X)
- Schroeder, L.A., 2021. Quantitative modelling of the Rural Development Programs of the Common Agricultural Policy - EU-wide and region-specific effects. University of Bonn.
- Schroeder, L.A., Gocht, A., Britz, W., 2015. The Impact of Pillar II funding: Validation from a Modelling and Evaluation Perspective. *Journal of Agricultural Economics* 66, 415–441. <https://doi.org/10.1111/1477-9552.12091>
- Shumway, C.R., Pope, R.D., Nash, E.K., 1984. Allocatable Fixed Inputs and Jointness in Agricultural Production: Implications for Economic Modeling: Reply. *American Journal of Agricultural Economics* 70, 950. <https://doi.org/10.2307/1241942>
- Simon, M., Letouzé, F., Colin, A., 2019. Evaluation de la biomasse bocagère en Normandie.

- Assessment of the bocage biomass in Normandy (in French).
- Simon, M., Letouzé, F., Colin, A., 2018. Evaluation de la biomasse bocagère en Bretagne. Assessment of the bocage biomass in Brittany (in French).
- Singbo, A., Larue, B., 2016. Scale economies, technical efficiency, and the sources of total factor productivity growth of Quebec dairy farms. *Canadian Journal of Agricultural Economics* 64, 339–363. <https://doi.org/10.1111/cjag.12077>
- Sobczyński, T., Klepacka, A.M., Revoredo-Giha, C., Florkowski, W.J., 2015. Dairy farm cost efficiency in leading milk-producing regions in Poland. *Journal of Dairy Science* 98, 8294–8307. <https://doi.org/10.3168/jds.2014-9030>
- Souchère, V., King, C., Dubreuil, N., Lecomte-Morel, V., Le Bissonnais, Y., Chalot, M., 2003. Grassland and crop trends: Role of the European Union Common Agricultural Policy and consequences for runoff and soil erosion. *Environmental Science and Policy* 6, 7–16. [https://doi.org/10.1016/S1462-9011\(02\)00121-1](https://doi.org/10.1016/S1462-9011(02)00121-1)
- Stetter, C., Sauer, J., 2022. Greenhouse Gas Emissions and Eco-Performance at Farm Level: A Parametric Approach. *Environmental and Resource Economics* 81, 617–647. <https://doi.org/10.1007/s10640-021-00642-1>
- Stiglitz, J.E., 2017. Overcoming the Copenhagen Failure with Flexible Commitments, in: *Global Carbon Pricing*. Massachusetts Institute of Technology.
- Stolze, M., Sanders, J., Kasperczyk, N., Madsen, G., Meredith, S., 2016. CAP 2014–2020: organic farming and the prospects for stimulating public goods.
- Tacconi, L., 2012. Redefining payments for environmental services. *Ecological Economics* 73, 29–36. <https://doi.org/10.1016/j.ecolecon.2011.09.028>
- Teisl, M.F., Roe, B., Hicks, R.L., 2002. Can eco-labels tune a market? Evidence from dolphin-safe labeling. *Journal of Environmental Economics and Management* 43, 339–359. <https://doi.org/10.1006/jeem.2000.1186>
- The World Bank, 2021. Carbon Pricing Dashboard | Up-to-date overview of carbon pricing initiatives [WWW Document]. The World Bank. URL https://carbonpricingdashboard.worldbank.org/map_data (accessed 2.7.22).
- Therond, O., Tichit, M., Tibi, A., Accatino, F., Biju-Duval, L., Bockstaller, C., Bohan, D., Bonaudo, T., Boval, M., Cahuzac, E., Casellas, E., Chauvel, B., Choler, P., Constantin, J., Cousin, I., Daroussin, J., David, M., Delacote, P., Derocles, S., De Sousa, L., Domingues Santos, J.P., Dross, C., Duru, M., Eugène, M., Fontaine, C., Garcia, B., Geijzendorffer, I., Girardin, A., Graux, A.-I., Jouven, M., Langlois, B., Le Bas, C., Le Bissonnais, Y., Lelièvre, V., Lifran, R., Maigné, E., Martin, G., Martin, R., Martin-Laurent, F., Martinet,

- V., McLaughlin, O., Meillet, A., Mignolet, C., Mouchet, M., Nozières-Petit, M.-O., Ostermann, O.P., Paracchini, M.L., Pellerin, S., Peyraud, J.-L., Petit-Michautn, S., Picaud, C., Plantureux, S., Poméon, T., Porcher, E., Puech, T., Puillet, L., Rambonilaza, T., Raynal, H., Resmond, R., Ripoche, D., Ruget, F., Rulleau, B., Rusch, A., Salles, J.-M., Sauvant, D., Schott, C., Tardieu, L., 2017. Volet “écosystèmes agricoles” de l’évaluation française des écosystèmes et des services écosystémiques (EFESE). “Agricultural ecosystems” component of the French assessment of ecosystems and ecosystem services (in French).
- Tiebout, C.M., 1956. A Pure Theory of Local Expenditures. *Journal of Political Economy* 64, 416–424.
- Tietenberg, T., 2003. *Environmental and Natural Resource Economics*: sixth edition.
- Tietenberg, T., Lewis, L., 2018. *Environmental and Natural Resource Economics*, 11th Edition. ed. Taylor & Francis.
- Tuomisto, H.L., Hodge, I.D., Riordan, P., Macdonald, D.W., 2012. Does organic farming reduce environmental impacts? - A meta-analysis of European research. *Journal of Environmental Management* 112, 309–320. <https://doi.org/10.1016/j.jenvman.2012.08.018>
- Uetake, T., 2014. Agri-environmental Management Through Collective Action. *EuroChoices* 13, 29–34. <https://doi.org/10.1111/1746-692X.12072>
- Uetake, T., 2013. *Managing Agri-Environmental Commons Through Collective Action: Lessons from OECD Countries*. Paris.
- Unay Gailhard, I., Bojnec, S., 2015. Farm size and participation in agri-environmental measures: Farm-level evidence from Slovenia. *Land Use Policy* 46, 273–282. <https://doi.org/10.1016/j.landusepol.2015.03.002>
- UNFCCC, 2016. Joint Implementation Project FR1000365: “Réduction des émissions de méthane d’origine digestive par l’apport dans l’alimentation des vaches laitières de sources naturelles en Acide Alpha Linoléique (ALA)” (in French). UNFCCC, Rio de Janeiro, New York.
- United Nations, 2015. Adoption of the Paris Agreement, in: 21st Conference of the Parties. Paris.
- United Nations, 1992. Convention on Biological Diversity. <https://doi.org/10.1016/B978-0-12-384719-5.00418-4>
- Uthes, S., Matzdorf, B., 2013. Studies on agri-environmental measures: A survey of the literature. *Environmental Management* 51, 251–266. <https://doi.org/10.1007/s00267-012->

- Vaissière, A.C., Tardieu, L., Quétier, F., Roussel, S., 2018. Preferences for biodiversity offset contracts on arable land: A choice experiment study with farmers. *European Review of Agricultural Economics* 45. <https://doi.org/10.1093/erae/jby006>
- van't Veld, K., Kotchen, M.J., 2011. Green clubs. *Journal of Environmental Economics and Management*, NBER working papers 62. <https://doi.org/10.1017/CBO9781107415324.004>
- van Amstel, M., Driessen, P., Glasbergen, P., 2008. Eco-labeling and information asymmetry: a comparison of five eco-labels in the Netherlands. *Journal of Cleaner Production* 16, 263–276. <https://doi.org/10.1016/j.jclepro.2006.07.039>
- Van Herzele, A., Gobin, A., Van Gossum, P., Acosta, L., Waas, T., Dendoncker, N., Henry de Frahan, B., 2013. Effort for money? Farmers' rationale for participation in agri-environment measures with different implementation complexity. *Journal of Environmental Management* 131, 110–120. <https://doi.org/10.1016/j.jenvman.2013.09.030>
- Van Huylenbroeck, G., Vandermeulen, V., Mettepenningen, E., Verspecht, A., 2007. Multifunctionality of Agriculture: A Review of Definitions, Evidence and Instruments. *Living Reviews in Landscape Research* 1, 1–43. <https://doi.org/10.12942/lrlr-2007-3>
- Vanslebrouck, I., Van Huylenbroeck, G., Verbeke, W., 2002. Determinants of the willingness of Belgian farmers to participate in agri-environmental measures. *Journal of Agricultural Economics* 53, 489–511. <https://doi.org/10.1111/j.1477-9552.2002.tb00034.x>
- Vatn, A., 2010. An institutional analysis of payments for environmental services. *Ecological Economics* 69, 1245–1252. <https://doi.org/10.1016/j.ecolecon.2009.11.018>
- Vatn, A., Kvakkest, V., Rørstad, P.K., 2002. Policies for Multifunctional Agriculture, the Trade Off between Transaction Costs and Precision.
- Verhoef, P.C., 2005. Explaining purchases of organic meat by Dutch consumers. *European Review of Agricultural Economics* 32, 245–267. <https://doi.org/10.1093/eurrag/jbi008>
- Verhulst, J., Kleijn, D., Berendse, F., 2007. Direct and indirect effects of the most widely implemented Dutch agri-environment schemes on breeding waders. *Journal of Applied Ecology* 44, 70–80. <https://doi.org/10.1111/j.1365-2664.2006.01238.x>
- Vermunt, D.A., Wojtynia, N., Hekkert, M.P., Van Dijk, J., Verburg, R., Verweij, P.A., Wassen, M., Runhaar, H., 2022. Five mechanisms blocking the transition towards 'nature-inclusive' agriculture: A systemic analysis of Dutch dairy farming. *Agricultural Systems* 195, 103280. <https://doi.org/10.1016/j.agsy.2021.103280>

- Villamayor-Tomas, S., Sagebiel, J., Olschewski, R., 2019. Bringing the neighbors in: A choice experiment on the influence of coordination and social norms on farmers' willingness to accept agro-environmental schemes across Europe. *Land Use Policy* 84, 200–215. <https://doi.org/10.1016/j.landusepol.2019.03.006>
- Villamayor-Tomas, S., Sagebiel, J., Rommel, J., Olschewski, R., 2021. Types of collective action problems and farmers' willingness to accept agri-environmental schemes in Switzerland. *Ecosystem Services* 50. <https://doi.org/10.1016/j.ecoser.2021.101304>
- Villanueva, A.J., Rodríguez-Entrena, M., Arriaza, M., Gómez-Limón, J.A., 2017. Heterogeneity of farmers' preferences towards agri-environmental schemes across different agricultural subsystems. *Journal of Environmental Planning and Management* 60, 684–707. <https://doi.org/10.1080/09640568.2016.1168289>
- Weill, P., Chesneau, G., Chilliard, Y., Doreau, M., Martin, C., 2009. Method to evaluate the quantity of methane produced by a dairy ruminant and method for decreasing and controlling this quantity. WO 2009/156453 A1.
- Weill, P., Schmitt, B., Chesneau, G., Daniel, N., Safraou, F., Legrand, P., 2002. Effects of introducing linseed in livestock diet on blood fatty acid composition of consumers of animal products. *Annals of Nutrition and Metabolism* 46, 182–191. <https://doi.org/10.1159/000065405>
- Westerink, J., Jongeneel, R., Polman, N., Prager, K., Franks, J., Dupraz, P., Mettepenningen, E., 2017. Collaborative governance arrangements to deliver spatially coordinated agri-environmental management. *Land Use Policy* 69, 176–192. <https://doi.org/10.1016/j.landusepol.2017.09.002>
- Wilkes, A., Wassie, S., Odhong, C., Fraval, S., van Dijk, S., 2020. Variation in the carbon footprint of milk production on smallholder dairy farms in central Kenya. *Journal of Cleaner Production* 265, 1–15. <https://doi.org/10.1016/j.jclepro.2020.121780>
- Wimmer, S., Sauer, J., 2020. Diversification economies in dairy farming - Empirical evidence from Germany. *European Review of Agricultural Economics* 47, 1338–1365. <https://doi.org/10.1093/erae/jbaa001>
- Wooldridge, J.M., 2010. Econometric analysis of cross section and panel data. <https://doi.org/10.2307/j.ctv5rdzwc.1>
- Wunder, S., 2015. Revisiting the concept of payments for environmental services. *Ecological Economics* 117, 234–243. <https://doi.org/10.1016/j.ecolecon.2014.08.016>
- Wunder, Sven, 2015. Revisiting the concept of payments for environmental services. *Ecological Economics* 117, 234–243. <https://doi.org/10.1016/j.ecolecon.2014.08.016>

- Wunder, S., 2005. Payments for environmental services: some nuts and bolts (No. 42), Occasional Paper. Bogor Barat. <https://doi.org/10.17528/cifor/001765>
- Zabel, A., Roe, B., 2009a. Optimal design of pro-conservation incentives. *Ecological Economics* 69, 126–134. <https://doi.org/10.1016/j.ecolecon.2009.08.001>
- Zabel, A., Roe, B., 2009b. Performance Payments for Environmental Services: Lessons from Economic Theory on the Strength of Incentives in the Presence of Performance Risk and Performance Measurement Distortion, IED. Zurich. <https://doi.org/10.2139/ssrn.1430419>
- Zavalloni, M., Raggi, M., Viaggi, D., 2019. Agri-environmental Policies and Public Goods: An Assessment of Coalition Incentives and Minimum Participation Rules. *Environmental and Resource Economics* 72, 1023–1040. <https://doi.org/10.1007/s10640-018-0237-9>
- Zavalloni, M., Viaggi, D., Dupraz, P., Letort, E., Le Gloux, F., Runge, T., 2022. Deliverable D4.4: Report on performance and design of solutions for the provision of AECPGs in value chain perspective. H2020 CONSOLE project.
- Zimmermann, A., Britz, W., 2016. European farms' participation in agri-environmental measures. *Land Use Policy* 50, 214–228. <https://doi.org/10.1016/j.landusepol.2015.09.019>

Titre : Analyse économique des paiements pour services environnementaux, entre label et mesure agro-environnementale

Mots clés : services environnementaux, bien public, politique agro-environnementale, étiquetage alimentaire, consentement à payer, consentement à recevoir

Résumé : Cette thèse de doctorat applique des approches microéconomiques empiriques et théoriques pour analyser l'efficacité des paiements pour services environnementaux dans le secteur agricole. J'évalue des leviers pour favoriser leur adoption par les agriculteurs à différentes échelles. Je montre empiriquement que cibler une partie des aides au revenu de la politique agricole commune vers un financement accru des mesures agro-environnementales et climatiques et du soutien à l'agriculture biologique favorise la participation à ces dispositifs. Ma principale contribution est de mettre en évidence qu'un bonus de parrainage dans les paiements pour services environnementaux est prometteur pour favoriser la participation d'une masse critique d'agriculteurs lorsqu'il existe des effets de seuils écologiques. Les résultats de cette thèse suggèrent aussi que des paiements

basés sur les résultats, sous forme de bonus collectif ou de paiement proportionnel à un indicateur environnemental, sont efficaces à la condition que le niveau de paiement soit suffisamment incitatif.

Avec une approche théorique, je m'intéresse à la demande et propose un outil, le label santé, pour augmenter le consentement à payer des consommateurs dans le cas particulier où la technologie de production jointe des services environnementaux est complémentaire à l'amélioration de la qualité intrinsèque du produit agricole en terme de santé. Je contribue à la littérature en montrant que les préoccupations de santé des consommateurs peuvent financer efficacement les services environnementaux et compléter les politiques agro-environnementales.

Title : Theoretical and empirical analysis of dedicated and food chain included payments for environmental services

Keywords : environmental services, public good, agri-environmental policy, food labeling, willingness to pay, willingness to accept

Abstract : This PhD thesis applies empirical and theoretical microeconomic approaches to analyse the efficiency of payments for environmental services in the agricultural sector.

I assess levers to promote their adoption by farmers at different scales. I show empirically that targeting part of the income support of the Common Agricultural Policy towards increased funding of agri-environmental and climate measures and support for organic farming promotes participation in these schemes. My main contribution is to show that a sponsorship bonus in payments for environmental services is promising to encourage the participation of a critical mass of farmers when ecological threshold effects

exist. The results of this thesis also suggest that result-based payments, in the form of a collective bonus or a payment proportional to an environmental indicator, are effective on the condition that the level of payment is sufficiently attractive.

With a theoretical approach, I focus on the demand side and propose a tool, the health label, to increase consumers' willingness to pay in the particular case where the joint production technology of environmental services is complementary to the improvement of the intrinsic health quality of the agricultural commodity. I contribute to the literature by showing that consumers' health concerns can efficiently finance environmental services and complement agri-environmental policies.