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**Exploring the Linkages between Agricultural Policies, Productivity and
Environmental Sustainability**

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Note by the Secretariat

In the Programme of Work and Budget (PWB) of the Committee for Agriculture (CoAg) for 2017-18, work on “Deepening the Framework for Analysing Policies for Innovation, Productivity and Sustainability in the Food and Agriculture Sector by Strengthening Policy Coherence” is mandated under the expected output result 3.2.3.1.2. A scoping paper for this project was presented to the JWPAAE in October 2017 [COM/TAD/CA/ENV/EPOC(2017)21]. This work-stream as a whole contributes to both qualitative and quantitative efforts to expand the analytical capacity of the OECD’s *Food and Agriculture Productivity-Sustainability Framework* (“the OECD framework”) (OECD, 2015^[1]; OECD, 2019^[2]), forming part of a suite of OECD work undertaken to strengthen this framework.

This work-stream consists of four main elements:

- i. a literature review on the effects of environmental policies on innovation, structural adjustment, productivity and sustainability performance in agriculture (OECD, 2019^[3]);
- ii. a literature review on the potential impacts of agricultural policies on environmental sustainability and productivity (DeBoe, 2020^[4]);
- iii. the improvement and expansion of the empirical model developed by OECD (2017^[5]); and
- iv. the testing of a complementary analytical approach to analyse complex causal relationships between government policies and productivity and sustainability performance using Fuzzy Set Qualitative Comparative Analysis (QCA).

This document was declassified by the JWPAAE under the written procedure following the October 2019 meeting.

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Executive Summary

This report explores the impacts of agricultural support policies and agri-environmental policies on productivity and environmental sustainability performance in agriculture. It draws on two detailed OECD literature reviews and presents two empirical applications aiming to address key gaps in the literature, as well as a synthesis for policy-makers. This work helps bridge the gap between research and policy, providing guidance on where the existing evidence yields reasonably clear policy recommendations, and where further research is needed.

Key findings

The report explores policy impact pathways and finds first that **productivity impacts** of agricultural and agri-environmental policies can occur via several avenues, which affect farmers' decision-making by changing relative prices of inputs and outputs, changing income constraints, changing risk exposure, or influencing structural change.

Environmental sustainability impacts of agricultural and agri-environmental policies similarly occur via affecting farmers' incentives in a range of decisions. Environmental pressures are the cumulative result of farmers' decisions on several economic 'margins': selection and intensity of input use (intensive margin); land-use allocation between agricultural activities (extensive margin); and land-use allocation between agricultural and other land uses (entry-exit margin). They also depend on farmers' decisions about producing ecosystem goods and services. Various factors beyond farmers' control also influence how pressures from agriculture translate into environmental outcomes.

Key findings on the productivity and sustainability impacts of agricultural support are:

- **Market price support, payments based on outputs, and payments based on unconstrained variable input use** generally produce negative environmental outcomes; the exception is where support changes the relative profitability of different outputs in a way which incentivises shifts towards lower-intensity land uses. These payment types are also generally found to have a negative impact on farm technical efficiency and productivity.
- Support **coupled to production** (e.g. payments based on outputs) generally has a negative impact on farm technical efficiency and productivity, as well as negative environmental impacts. Negative environmental impacts of coupled support are a particular concern for high-intensity agricultural systems, where existing high input use combined with policy signals to further intensify are more likely to result in environmental pressures exceeding natural attenuation capacity thresholds.
- **Payments based on current area** can provide an incentive to maintain marginal land in production: the environmental sustainability impacts of this depend on contextual factors such as whether land is simply abandoned, or converted to potentially more environmentally-friendly land uses. **Payments based on current area or animal numbers** affect environmental pressures via the extensive and entry-exit margins. Thus, they could have environmentally positive impacts if support shifts towards land uses with relatively lower intensity.

- **Decoupled payments** generally do not affect incentives at the intensive or extensive margin, but may affect incentives at the entry-exit margin. Specifically, decoupled payments may supplement incomes and thereby improve the viability of agricultural enterprises, dampening incentives to shift to other land uses.
- Past policies, in combination with other factors, have in several OECD countries produced agricultural production systems which are **highly intensive**, and which have **large negative environmental impacts**, particularly in terms of nutrient runoff and greenhouse gas emissions.

Hence, these findings show that production-related income support measures perform poorly with respect to productivity as well as environmental sustainability. Production-coupled support generally has a negative impact on farm technical efficiency and productivity, and negative environmental impacts, particularly on highly productive land. Further, given evidence of a negative relationship between farm dependency on support and technical efficiency, there may be a trade-off between productivity objectives and other objectives related to supporting farm incomes.

Decoupling agricultural support from production removes distortionary incentives for intensification, but does not internalise negative environmental externalities of agricultural production. Decoupling support from production allows farmers to respond to incentives provided by the market. However, given that prices often do not take into account environmental externalities associated with agricultural production, market forces cannot be relied on to incentivise a shift towards *lower* intensity and smaller negative environmental impacts. Thus, decoupling on its own is unlikely to solve environmental problems related to production structures and intensity in cases where structures are sub-optimal from an environmental perspective and intensities are high due to past policies and current market price ratios.

This study employs the OECD Producer Support Estimate (PSE) classification of agricultural support policies. The PSE classification has some drawbacks when analysing environmental impacts of policies, in particular that the PSE categories and labels do not distinguish between different kinds of constraints or other policy design features which could be expected to have different environmental impacts. Thus, in order to evaluate specific policies, it would be important to have more information, for example, on the type of input being constrained and the level of the constraint.

Policy recommendations

- In countries with high intensity production systems, both shifting from environmentally harmful support towards more targeted agri-environmental policies *and* adding stronger environmental cross-compliance criteria to remaining agricultural support are warranted in order to minimise harmful environmental impacts of agricultural support policies.
- Better policies are needed to prevent and address land-use homogenisation and land abandonment, and to address landscape-scale environmental issues, particularly where the spatial configuration of production or environmental management actions matters for environmental outcomes. Policy-makers need to take a more holistic approach and consider how individual policy instruments interact and their impacts at a landscape level. In general, recent reforms have focussed on mitigating negative environmental impacts (“environmental bads”) of existing policies; there

is a need for augmented policy focus on *increasing* the production of environmental and other public goods (e.g. cultural goods) from agriculture.

- Environmental regulations can play a positive role in the policy mix, and do not necessarily involve a trade-off between productivity and sustainability. Regulation can in some cases spur innovation that provides economic benefits which outweigh compliance costs, or lead to improved farm performance via impacting consumer demand. Where ‘green technology’ displays public good characteristics, regulations can also be an important co-ordination tool.
- More research is needed which clearly identifies key instrument features in terms of their specific productivity and environmental impacts , and which clearly distinguishes mandatory environmental conditions accompanying agricultural support payments.

Part I: Synthesis for Policy-makers

Part I synthesises findings and policy recommendations on the productivity and environmental sustainability impacts of agricultural support policies from four sources. These sources are: two OECD literature reviews (OECD, 2019^[3]) (DeBoe, 2020^[4]) and two empirical applications (presented in Part II below).

This synthesis is designed to be read in conjunction with the four underpinning evidence sources, and as such generally omits citations to works that are reviewed in those sources.

1. Linkages between agricultural policies, productivity and environmental sustainability in agriculture

1. Agriculture is a significant source of pressures on the environment. Policy-makers have committed themselves to delivering better policies to help improve the environmental sustainability of the sector, at the same time as delivering productivity growth. In order to achieve this, policy-makers need to understand how current and potential new policies affect agricultural productivity growth and environmental sustainability.

2. A vast range of relevant theoretical and empirical evidence has been produced over many decades, and by researchers in many countries, both within and beyond the OECD area. Clearly, a single report cannot provide definitive, complete guidance for policy-makers. Nevertheless, the intent of this report is to explore this evidence base, while at the same time helping consolidate this evidence into a form that is more digestible for policy-makers (Box 1.1 provides an overview of evidence sources underpinning this chapter). In this way, it helps bridge the gap between research and policy, providing guidance on where the existing evidence yields reasonably clear policy recommendations, and where further research is needed. Further, it considers simultaneously economics and environmental aspects, bringing together disparate knowledge about the impacts of agricultural support policies from several different fields, as well as two new empirical analyses.

Box 1.1. Evidence sources underpinning this report

The evidence sources underpinning this synthesis are:

- An OECD literature review on the effects of environmental policies on innovation, structural adjustment, productivity and sustainability performance in agriculture (OECD, 2019^[3]).
- An OECD literature review on the potential impacts of agricultural policies on environmental sustainability and productivity (DeBoe, 2020^[4]).
- Results from the application of an empirical **farm-level model** developed by OECD (2017^[5]) (described in Chapter 2 in this report) using data from the EU context. This application jointly considers sustainability and productivity impacts of selected agricultural support instruments.
- Results from an exploratory application of a complementary analytical approach to analyse complex causal relationships, known as **Fuzzy Set Qualitative Comparative Analysis (QCA)** (Chapter 3 in this report). This approach allows consideration of how policy packages affect sustainability and productivity outcomes, using an *ex post* approach based on OECD agri-environmental indicators and related data gathered via the OECD's sustainable productivity reviews. To date, QCA is rarely employed in economics, and even less so in the context of agricultural and agri-environmental policies, and thus this analysis constitutes a test of this methodology with a view to potentially expanding the policy analysis toolbox of the OECD.

The two empirical components were undertaken to contribute towards filling several gaps identified in the literature:

- Most empirical work analysing the impacts of agricultural and agri-environmental policies considers either (environmental) sustainability or productivity impacts, but rarely are both considered together.
- Many studies that analyse impacts of agricultural support instruments do not contain sufficient detail on instruments studied to allow identification of how specific features of the instrument design affect productivity and sustainability outcomes. For example, many *ex post* studies consider “total support” as an explanatory variable, which prevents analysis of the impacts of different kinds of support. Another example is that studies analysing “coupled support” rarely distinguish that basis of that support (i.e. whether support is based on current area or animal numbers, output value, receipts, etc.).
- While there are a large number of *ex ante* scenario modelling studies which estimate impacts of policy packages under various hypothetical policy reform scenarios, there are fewer studies which examine complex causal pathways using *ex post* approaches—the QCA analysis is one tool to undertake such an analysis.

The two empirical components are intended to complement each other. The farm-level modelling allows detailed *ex ante* consideration of the estimated environmental and productivity impacts of specific payment types, holding other factors constant. The QCA approach allows *ex post* consideration of how the policy mix as a whole, in addition to other factors such as the existing structure of the agricultural sector, have combined to produce different environmental and productivity outcomes in the studied countries. Together, these components allow a richer understanding of the existing pathways which have produced the environmental and productivity outcomes existing today, and provide insight about likely outcomes that policy reform could produce in the future.

A conceptual framework for analysing policy impacts on productivity and sustainability in agriculture

3. Agricultural policies can in theory produce both positive and negative economic impacts and environmental impacts. Policy impacts can be direct, indirect, and dynamic (i.e. impacts may change over time). This section provides a conceptual overview of the key pathways via which policies impact productivity and environmental sustainability in agriculture. It also defines key terms and discusses the different components of ‘sustainable productivity’ in agriculture.

What do we mean by ‘sustainable productivity’ in agriculture?

4. Governments have repeatedly called for a renewed focus on ‘sustainable productivity’ growth in agriculture (OECD, 2016^[6]). Yet, *sustainable productivity* is a multi-faceted concept, and different conceptions abound. In the context of the United Nations Sustainable Development Goals, sustainability itself is a multi-faceted concept, encompassing economic, environmental and social components.

5. In the OECD’s *Food and Agriculture Productivity-Sustainability Framework* (‘the OECD framework’), ‘sustainable productivity’ refers to “productivity growth compatible

with the preservation of natural capital in the short and long run” (OECD, 2015, p. 5_[1]).¹ Within this definition, ‘natural capital’ refers to “natural assets in their role of providing natural resource inputs and environmental services for economic production”. Thus, ‘sustainability’ in the OECD framework, as in this report, essentially refers to *environmental* sustainability. This definition encompasses both managing agriculture’s use of natural resources to ensure their long-term viability, and reducing negative environmental impacts of agriculture production. Sustainable agricultural production systems also need to account for long-term impacts, such as the uncertain impacts of climate change (OECD, 2019_[2]).

6. The notion that sustainable productivity maintains the *long-term viability* of natural resources implies that the existence of environmental or natural capital thresholds, below which natural resources are not viable in the long-run. This means that natural resources, whether considered as inputs to agricultural (or other) production systems, or as output valued by society, may not be perfectly substitutable, between each other or between other kinds of inputs or outputs. There is ongoing debate over such degrees of substitutability, with the result that there are several differing definitions of ‘environmental sustainability’ (Box 1.2 provides definitions for this and other key concepts used in this report). In the empirical applications presented in this report (Part II), the analysis explicitly takes account of different definitions of environmental sustainability, in particular including ‘weak sustainability’ (perfect substitution between all inputs and outputs), ‘semi-strong sustainability’ (limited substitutability) and ‘strong sustainability’ (highly limited substitutability). This work yields useful insights about how assessments of agricultural sustainability depend on the assumptions made and sustainability definitions used.

7. The OECD framework takes a similarly holistic view of ‘productivity’, which is defined as Total Factor Productivity (TFP), a concept which considers the efficiency with which firms combine all inputs to produce outputs. Conceptually, this notion of productivity extends to including natural resources and environmental goods and services. Therefore, progress towards sustainable productivity could be measured by considering holistic TFP measures, such as ‘environmentally-adjusted TFP’ (EATFP).² However, in practice most TFP measures at best include environmental elements only partially (OECD, 2019_[2]), and agreement at the international level about how EATFP indices should be formulated remains a work in progress. In fact, an important part of the OECD co-ordinated Network’s on Agricultural Total Factor Productivity and the Environment activities is the development of methodological and practical guidance (Manual) that member countries

¹ See <http://www.oecd.org/tad/agricultural-policies/innovation-food-agriculture.htm>.

² According to the OECD, “Conventional productivity measures often only account for those inputs and outputs for which there are market transactions, while the role of the environment in production is not taken into account. This omission can be a source of systematic bias in productivity calculations and can contribute to incorrect interpretations of the results and subsequent policy conclusions. A comprehensive total factor productivity (TFP) indicator [i.e. environmentally-adjusted TFP] that accounts for the use of natural resources and production of undesirable environmental outputs is needed”. See <https://www.oecd.org/agriculture/events/environmentally-adjusted-total-factor-productivity-in-agriculture-14-december-2015.htm>, accessed September 2019.

can use to construct productivity accounts for the measurement of TFP and EATFP trends.^{3,4}

8. In the literature, few studies use a holistic measure of sustainable productivity in agriculture. In fact, most studies only analyse productivity *or* environmental sustainability aspects, and even those which do include both aspects still mostly consider environmental and economic aspects separately.⁵ Moreover, most studies do not attempt to evaluate agriculture's effects on the long-term viability of natural resources (as encompassed by the OECD framework definition of sustainable productivity); rather, they tend to focus on various economic or environmental 'performance' metrics, which yield insight on the current or projected future outcomes in terms of specific economic or environmental variables. Indeed, many different conceptions that can broadly fit within the notions of 'environmental performance' and 'economic performance' exist in the literature. Environmental performance can encompass participatory metrics such as: implementation of some kind of farm-level environmental management strategy (without linking this to a particular physical impact); implementing specific production methods (e.g. conservation tillage or other "best management practices"); generally reducing input use (e.g. land retirement, decreasing water, fertiliser or nutrient inputs etc.); or achieving measured environmental gains (e.g. reducing nutrient runoff to downstream water bodies). Similarly, economic performance encompasses measures of productivity, competitiveness, economic efficiency (technical, allocative and dynamic), and financial profitability.

9. The OECD framework focuses specifically on *productivity growth* when considering economic performance, as this is a holistic measure that considers the creation of economic value for a given level of inputs, and moreover is a concept which lends itself to empirical quantitative analysis. However, this focus on productivity growth does not necessarily allow for explicit analysis of aspects which may be of concern to policymakers – in particular profitability and producer surplus measures which relate to productivity but which are also influenced by the distribution of economic surplus throughout agri-food supply chains.

³ For more details see the Network's web site: <http://oe.cd/eatfp>.

⁴ TFP focuses on the quantity of outputs but does not reflect quality of outputs.

⁵ Social dimension of sustainability is also rarely considered in these studies.

Box 1.2. Key concepts and definitions used in this report

This report makes use of the following key concepts and defined terms.

Allocative efficiency: according to Bokusheva and Čechura (2017^[7]), “allocative efficiency reflects the ability of a firm to use the right combination of inputs (*input allocative efficiency*) or to produce the right mix of outputs (*output allocative efficiency*) given the set of prices. An allocatively efficient farm chooses outputs and inputs in combinations that maximise its profit at given prices.” Allocative efficiency occurs when the input-output combination is cost-minimising and/or profit-maximising. Allocative inefficiency arises when the input mix is not consistent with cost minimisation; that is, when farmers do not equalise marginal returns with true factor market prices. In the case of a multiple-output industry (such as agriculture), one may also consider the allocative efficiency of the output mix.

Cost-effectiveness: the least cost option for meeting a specified objective or outcome. Cost-effectiveness can be assessed at various scales (e.g. farm-level, landscape-level, regional-level, etc.), but should include all relevant costs; i.e. indirect costs and administrative costs (transactions costs) should be included as well as direct costs (see Balana, Vinten & Slee (2011^[8]) and OECD (2010^[9])).

Environmental effectiveness: the capacity of the instruments to achieve stated environmental goals or targets of practices (OECD, 2010^[9]). In this report, the concept applies to agri-environmental policy instruments. Börner et al. (2017^[10]), together with Hardelin and Lankoski (2018^[11]), define five main factors determining environmental effectiveness of policies:

- Programme costs (i.e. transaction and implementation costs).
- The direct changes in land or resource use induced by the programme, compared to the counterfactual without the programme.
- Indirect changes in land or resource use (e.g. spillovers onto land outside of the programme), compared to the counterfactual.
- The effects these changes in land and resource use have on the actual provision of environmental good and services.
- Political feasibility (e.g. of defining, or implementing, an instrument which achieves substantive change).

Environmental impacts or environmental effects refer to specific environmental pressures (‘environmental bads’) or environmental ‘goods’ arising from agricultural production systems. Examples of environmental pressures include agricultural greenhouse gas emissions, nutrient emissions or other water quality impairment, soil erosion and biodiversity loss caused by agricultural intensification or conversion of land for agricultural uses. Examples of environmental ‘goods’ (often also referred to as ‘ecosystem services’) include carbon storage, preservation of rural landscapes, resilience to natural disasters (such as flooding, landslides, fire and snow damage), pollination and soil functionality (OECD, 2018^[12]), as well as habitat provision and control of invasive species. It should be acknowledged that a given policy may have multiple environmental impacts, potentially both contributing to and detracting from overall agricultural sustainability performance.

Environmental sustainability

- ***Weak sustainability*** is a sustainability concept which assumes there is perfect substitutability between different kinds of inputs (natural resources including assimilation capacity, capital, labour, land, fertilisers, etc.), and also between different kinds of outputs (e.g. between environmental goods and services and agricultural commodities) (Bowen, 2016_[13]). Given this perfect substitutability between natural capital and other inputs, weak sustainability may be inconsistent with achievement of specific environmental objectives relevant for agriculture. Thus, this report includes weak sustainability measures primarily for the purpose of providing a point of comparison with ‘stronger’ sustainable productivity concepts.
- ***Semi-strong sustainability*** allows substitution between environmental and other production inputs, but does not allow substitution between different environmental dimensions (i.e. assumes limited substitutability between environmental inputs to the agricultural production process). This report develops and tests semi-strong sustainability as part of the QCA analysis in Chapter 3 to analyse how different sustainability concepts affect countries’ ability to achieve high sustainable productivity.
- ***Strong sustainability*** requires that some certain specific elements of natural capital are preserved, on the basis that there are certain functions that the environment performs that cannot be duplicated by humans or manufactured capital (Bowen, 2016_[13]). This means that there is limited substitutability between different types of inputs (both within environmental inputs, and between environmental and other production inputs) in agricultural production systems.

Entry-exit margin the allocation of land between cultivated agricultural land and other land uses, such as, idled land, forestry, or conservation areas. Changes at the entry-exit margin affect environmental outcomes because, for example, conversion of forestland or grasslands to cultivated cropland increases nutrient runoff and decreases carbon sinks.

Extensive margin refers to land-use allocation between different agricultural activities. Changes at the extensive margin affect environmental outcomes because, for example, nutrient runoff and GHG emission profiles differ between cereals and grasslands.

Intensive margin refers to the selection of inputs and the intensity with which inputs are used. Changes at the intensive margin affect environmental outcomes because, for example, use of chemical fertiliser and manure can lead to increased nutrient runoff and greenhouse (GHG) emissions per hectare or per unit of output.

Technical efficiency: Full technical efficiency characterises a production process where the maximum possible output has been achieved, given a fixed set of inputs and given a certain technology (OECD, 2001_[14]). Technical inefficiency arises when actual or observed output from a given input mix is less than the maximum possible. Technical efficiency gains are thus a movement towards “best practice”,¹ in the sense a production process has achieved the maximum amount of output that is physically achievable with current technology, and given a fixed amount of inputs.

Total factor productivity (TFP): also called multifactor productivity (MFP), measures the efficiency with which firms combine all inputs to produce outputs, as the ratio of total outputs relative to total inputs. As such, TFP is a single measure designed to capture how

efficiently a farm uses total inputs to produce outputs. Unless otherwise stated, a reference to ‘productivity’ in this report is a reference to TFP.

Note: 1. In technical terms, that production is occurring on the production possibilities frontier.

Sources: Balana, Vinten & Slee (2011^[8]), Bokusheva and Čechura (2017^[7]), Börner et al. (2017^[10]), Bowen (2016^[13]), Coelli et al. (2005^[15]), Fan (1999^[16]), Hardelin and Lankoski (2018^[11]), Kimura and Sauer (2015^[17]), Latruffe (2010^[18]), OECD (2001^[14]), OECD (2010^[9]) and OECD (2018^[12]),

Productivity and technical efficiency impacts of agricultural policies

10. Agricultural productivity, and the related concept of technical efficiency, are the outworking of farmers’ individual decision-making, combined with other factors such as initial resource endowments, climatic factors (e.g. rainfall, temperature) and economic factors (e.g. price fluctuations).

11. Beginning at the level of individual decision-making on-farm, four main pathways via which policies directly affect farmers’ decision-making are identified in the literature:

- *Changing relative prices of inputs and outputs*, affecting farmers’ choices about what to produce and how to produce it (e.g. purchased input use; land use; labour use, including on-farm versus off-farm labour decisions; technology choice, etc.).
- *Increasing or reducing income constraints (income or wealth effects)*, which may in turn affect decisions about investment and input use, particularly decisions about labour allocation, and may alter incentives to produce efficiently or adopt productivity-enhancing innovations (effort effect).
- *Increasing or reducing risk exposure (insurance effect)*, which may alter incentives to produce efficiently or adopt productivity-enhancing innovations, or incentives to adapt to risks such as climate change (moral hazard effect, potential for adaptation or maladaptation).
- *Influencing structural change* (farm entry and exit, changes in farm size, and innovation or technical change).

12. Impacts via these main pathways may be the product of various specific mechanisms: for example, policy impacts via changing relative prices of inputs will be a combination of at least income and substitution effects. Moreover, impacts via these main pathways may offset or reinforce one another.

13. Individuals’ responses to agricultural policies can also be mediated by a range of factors, including: individual or farm characteristics (e.g. natural capital, education levels, age, attitude towards environmental outcomes and risk); market settings (e.g. degree of competition); institutional settings (e.g. the types of agricultural policies used and the coherence of various policy measures, policy eligibility criteria and timing, property rights, legal frameworks, cultural institutions, and interactions with other policies and regulations, such as regulations governing taxation, trade, labour markets, and environmental quality); and exogenous shocks such as climate change impacts. This means that individual responses to specific agricultural policies are likely to differ. Differences also may be spatially correlated due to location-specific factors, particularly natural capital and landscape characteristics.

14. Further, direct effects on farmers’ decision-making via these pathways can be amplified or mitigated by feedback mechanisms, as the aggregated effect of individual

decisions changes market outcomes. For example, at a regional, national or international level, the sum of individual production decisions can affect commodity and land prices, which feed back into individuals' further decisions. At a sectoral or regional level, agricultural policies can also alter the relative competitiveness of different farming methods (e.g. organic versus conventional production methods), or of farming on land with specific physical characteristics (e.g. High Nature Value or Less Favoured Area land). Links might also be in the opposite direction, for example, Hailu and Poon (2017^[19]) identify that less efficient firms may be more likely to enrol in voluntary payment programmes, which may in turn increase their profitability or reduce risk of exit.

15. This work does not attempt to assess the significance of agricultural policy impacts on productivity or environmental performance in agriculture relative to impacts from other sources (e.g. market price fluctuations, non-agricultural policies). However, it should be recognised that both productivity and environmental outcomes in agriculture are influenced by other drivers than agricultural policy. These drivers include other kinds of policy, as well as non-policy factors, such as technology availability and choice, farmer characteristics and preferences (including risk preferences), consumption preferences, climate conditions and variability, etc. These drivers are not the focus of this current work, but they clearly influence productivity and environmental outcomes for agriculture directly or via mediating the impacts of policy drivers. Finally, this study does not consider the impact of agricultural policies on the social dimension of sustainability.

Environmental impacts of agricultural policies

16. Agricultural policies can similarly produce both negative and positive impacts on the environmental performance of agriculture. Negative environmental impacts of agricultural policies occur via several pathways. At the farm level, key pathways identified in the literature are:

- Incentivising an increase in production on the *intensive margin*:
 - increased input use intensity, particularly use of synthetic pesticides, herbicides and fertiliser can lead to increased toxic chemical, nutrient and greenhouse emissions per unit of utilised agricultural area (UAA) or per unit of output;
 - effects from increasing livestock numbers per UAA unit can increase environmental degradation associated with livestock, including ruminant GHG emissions, soil erosion (e.g. gully formation due to livestock), spread of invasive species in grazing lands, nutrient emissions from manure and urine patches, etc.
 - increased water use (e.g. for irrigated agriculture) can result in a range of environmental impacts, including salinity, surface and groundwater depletion, and biodiversity loss due to loss of freshwater habitats.
- Incentivising an increase in production on the *extensive margin* or *entry-exit margin*:
 - expansion of agricultural areas (or conversion of fallow or low-intensity agricultural land uses towards more intensive agricultural uses) can cause severe environmental harm, by destroying habitats and causing significant biodiversity loss, decreasing carbon sinks, increasing erosion, etc.
 - however, if not managed well, contraction of agricultural land can lead to land abandonment which can also have negative environmental impacts including

negative impacts of invasive species, increased risk of wildfire, erosion (if abandoned land lacks adequate soil cover). Contraction of agricultural land may also induce further intensification on remaining agricultural land.

- Long-term impacts of land use choice such as impact of cropping choices (spatial and temporal diversity), tillage practices, frequency and type of crop rotations, farm entry and exit decisions, etc. Long-term impacts can operate via a change in the intensive, extensive or exit-entry margins, or some combination of the three. Potential environmental impacts of changes in the three margins are described above.

17. Agricultural policies may also produce positive environmental impacts. Pathways for positive impacts include incentivising the *opposite* of the effects described above; such pathways can be characterised as incentivising the reduction of negative impacts of agriculture.⁶ Further, agricultural activity can also produce valuable environmental goods. Thus, another avenue for policies to influence agriculture’s environmental performance is to incentivise production of *environmental goods*, also referred to as “ecosystem services” or “multifunctionality”.⁷ Examples of environmental goods that can be produced by agriculture are carbon storage, preservation of rural landscapes, resilience to natural disasters (such as flooding, landslides, fire and snow damage), pollination and soil functionality, as well as habitat provision and control of invasive species.

18. Environmental impacts of agricultural policies depend on a number of different factors. First, environmental impacts vary because individual responses to economic incentives created by agricultural policies vary, as described above. Second, environmental impacts of individual decisions vary due to a wide range of location-specific physical factors, including landscape characteristics (soil type, slope, aspect, proximity to water bodies or aquifers, precipitation, attenuation capacity of land and receiving water bodies, etc.). Environmental impacts also depend not only on individual actions but on the cumulative effects of decisions across actors and across time, and also may depend on physical thresholds and complex bio-physical linkages. Finally, environmental impacts may differ depending on whether they are considered at a local, landscape, regional, national or global scale.

⁶ In economic terms, in this case the policies can be characterised as reducing incentives for the agricultural sector to produce environmental ‘bads’.

⁷ The OECD’s working definition of ‘multifunctionality’ associates multifunctionality with particular characteristics of the agricultural production process and its outputs: i) the existence of multiple commodity and non-commodity outputs that are jointly produced by agriculture; and ii) that some of the non-commodity outputs may exhibit the characteristics of externalities or public goods, such that markets for these goods function poorly or are non-existent. (OECD, n.d.^[35]). Merckx and Pereira (2015^[34]) express concern, however, that policy-makers have used the concept of multifunctionality to promote an understanding in which agriculture is seen as necessary to provide certain environmental goods (e.g. biodiversity), in order to justify high levels of support. This could be seen as a combination of focussing on agricultural production of environmental goods at the expense of environmental bads and at the expense of alternative landuse options (the authors focus on “rewilding”) which may deliver “better” (e.g. higher quality) environmental goods.

Distinguishing policy impacts by policy instrument type

19. For *agricultural support policies*, impacts are examined using a categorisation based on the OECD's Producer Support Estimates (PSE) classification of policy types, including use of PSE labels where relevant to differentiate productivity or environmental policy impacts. This classification is based implementation criteria reflecting the economic features of policy measures, which are important for the potential impacts of policies on production, income, consumption, trade, and the environment. Within the PSE classification, policy measures are classified into seven categories, which identify the transfer basis for the policy, whether the basis is current or non-current, and whether production is required or not. The PSE categories are:⁸

- A. Support based on commodity outputs
- B. Payments based on input use
- C. Payments based on current A/An/R/I, production required
- D. Payments based on non-current A/An/R/I, production required
- E. Payments based on A/An/R/I, production not required
- F. Payments based on non-commodity criteria.
- G. Miscellaneous payments.

20. It is acknowledged that the PSE classification has some drawbacks when analysing environmental impacts of policies, in that the PSE categories and labels do not distinguish between different kinds of constraints or other policy design features which could be expected to have different environmental impacts (OECD, 2016_[20]). Therefore, where possible this review identifies how environmental impacts differ within as well as across PSE categorisations. This extends earlier OECD work where PSE categories were ranked according to their potential environmental impact (OECD, 2013_[21]).

21. For *environmental policies* in agriculture, the review focuses on commonly-used environmental policy instruments used in agriculture (Table 1.1). These instruments can be broadly categorised into *regulatory instruments*, which directly impose environmental requirements on farmers; *hybrid instruments*, which impose environmental requirements as a condition for participation in other (non-environmental) policy measures; and *economic instruments*, which incentivise farmers to provide environmental services (improve their environmental performance). While policy instruments may affect several sectors of the economy, this review provides evidence relating to environmental policies that are specific to the agriculture sector (referred to here as “agri-environmental policies”).

⁸ Within the PSE categorisation, A, An, R and I respectively indicate area, animal number, receipts, and income. Corresponding to these PSE characteristics, there are also PSE “labels” including current commodity production and payment limits (Limit/No limit), payment rates (Fixed/Variable), input constraints (with, mandatory or voluntary, on animal welfare, the environment, etc.), payment eligibility (based on area, animal number, receipts, income), commodity(ies) (single, group, all), and production exceptions (with or without). See <http://www.oecd.org/agriculture/topics/agricultural-policy-monitoring-and-evaluation/documents/producer-support-estimates-manual.pdf>, accessed March 2019.

Table 1.1. Selected agri-environmental policy instruments

Category	Instrument	Examples
Regulatory instruments	Environmental standards	Input standards, technology standards, performance (output) standards
Hybrid instruments	Environmental “cross-compliance” ¹ requirements	Cross-compliance mechanisms, baseline eligibility requirements
Economic Instruments	Agri-environmental payment schemes	Payments for environmentally sustainable on-farm practices, public investment in structural adjustment towards “greener” agricultural systems
	Environmental taxes and tariffs	Performance taxes, input taxes, water tariffs
	Tradeable allowances	Emissions trading schemes, tradeable offset schemes, water markets, in lieu fee programs
	Publicly-funded investment in property rights for the environment	Purchase of water rights from agricultural enterprises, with purchased rights being allocated to the environment

Note: See OECD (2010_[22]) for an overview of “cross-compliance” mechanisms in agriculture.

Source: Adapted from OECD (2010_[9]) and Hardelin and Lankoski (2018_[11]).

How do different policy instruments affect productivity and environmental performance in agriculture?

Agricultural support instruments

22. Table 1.2 summarises findings from the literature reviews (OECD, 2019_[3]) (DeBoe, 2020_[4]), and the empirical applications presented in Chapters 2 and 3, by PSE category. Agri-environmental payments are also be discussed further below.

Table 1.2. Summary of farm-level efficiency, productivity and environmental impacts of market price support and payments based on output

Policy type	Effect on technical efficiency (ETE) and productivity (EP)	Environmental effects (EE)
A1. Market price support (MPS)	<ul style="list-style-type: none"> • Trade-based MPS measures (e.g. tariffs): negative EP. • Production quotas: generally negative ETE and EP as binding quota constrains scale efficiencies; negative productivity impacts can be partially mitigated by allowing quotas to be traded. • Administered price: evidence from studies evaluating deregulation reforms indicates generally negative EP. 	<ul style="list-style-type: none"> • Direct incentive to increase production of the supported commodities likely to cause negative EE on land used for those commodities, e.g. via land clearing or intensification. • Where MPS supports a specific commodity or sector, overall environmental impacts depend on the environmental outcomes associated with different land uses: if on balance MPS incentivises a shift towards lower-intensity land uses, overall environmental impacts from MPS may be positive. Overall assessments need to take into account shifts between agricultural land uses (e.g. pasture versus cropping), and also between agricultural and non-agricultural land uses. • Reduction in MPS may lead to land abandonment, which may have negative impacts on biodiversity and landscape ecology, as well as further intensification on remaining agricultural land. These impacts need to be carefully considered when pursuing policy reform; policy-makers may need to manage land use transitions resulting from policy reform more pro-actively and reforms may need to include specific measures to address specific environmental externalities.

Policy type	Effect on technical efficiency (ETE) and productivity (EP)	Environmental effects (EE)
A2. Payments based on commodity output	<ul style="list-style-type: none"> Coupled output support: generally negative ETE and EP Long-term impacts: positive bias towards commodities which have high levels of MPS over time, for development of productivity-improving innovations. 	<ul style="list-style-type: none"> Direct incentive to increase production likely to cause negative EE on land used for supported commodities, e.g. via land clearing, conversion of marginal land to cropland, conversion of pasture to cropland, or intensification. Where output-based support focuses on a specific commodity or sector, overall environmental impacts depend on the environmental outcomes associated with different land uses: if on balance support incentivises a shift towards lower-intensity land uses, overall environmental impacts from support may be positive. Overall assessments need to take into account shifts between agricultural land uses (e.g. pasture versus cropping), and also between agricultural and non-agricultural land uses. Reduction in output-based coupled support may lead to land abandonment, which may have negative impacts on biodiversity and landscape ecology, as well as further intensification on remaining agricultural land. These impacts need to be carefully considered when pursuing policy reform; policy-makers may need to manage land use transitions resulting from policy reform more pro-actively and reforms may need to include specific measures to address specific environmental externalities.
B1. Payments based on input use (variable)	<ul style="list-style-type: none"> Generally negative ETE and EP as payment distorts production choices in favour of subsidised input use away from technically efficient input combinations 	<ul style="list-style-type: none"> Payments based on water, pesticide, fertiliser or fuel use provide direct incentive to increase use of subsidised inputs and intensify production, which is likely to cause negative EE; if these types of payments are used, mandatory environmental constraints may help mitigate negative EE, but they need to be well-designed and binding. Positive EE if “environmentally friendly” inputs (or practices) are subsidised, such as integrated pest management, soil and water conservation practices. Can incentivise land-use change—e.g. incentivise conversion of grassland to crops., resulting in biodiversity loss and increased environmental pressures
B2. Fixed capital formation	<ul style="list-style-type: none"> Investment support: mixed evidence, both in general and also for investment for adaptive and environmental capital. 	<ul style="list-style-type: none"> EE depends on type of capital subsidised E.g. Subsidised irrigation infrastructure can incentivise increased water use; subsidised livestock management structures (e.g. off-stream watering, waterway fencing) can have positive EE.
B3. On-farm services	<ul style="list-style-type: none"> Neutral or positive EP. 	<ul style="list-style-type: none"> Depends on how on-farm services changes farm management practices and input use. Positive EE if targeted towards improving conservation on-farm or facilitating adoption of environmentally-beneficial technologies.
C1. Payments based on current A/An/R/I, production required—current receipts / income)	<ul style="list-style-type: none"> Coupled payments: negative ETE. 	<ul style="list-style-type: none"> Indirect incentive to increase herd size or cropping area, likely to cause negative local EE such as increased emissions per unit of land (to both air and water). Incentive to maintain marginal land in production: environmental impacts of this depend on contextual factors. Where support focuses on a specific commodity or sector, overall environmental impacts depend on the environmental outcomes associated with different land uses: if on balance support incentivises a shift towards lower-intensity land uses, overall environmental impacts from support may be positive. Overall assessments need to take into account shifts between agricultural land uses (e.g. pasture versus cropping), and also between agricultural and non-agricultural land uses

Policy type	Effect on technical efficiency (ETE) and productivity (EP)	Environmental effects (EE)
C2(a). Payments based on current A/An/R/I, production required—current area)	<ul style="list-style-type: none"> • Coupled payments: generally negative ETE. • Subsidised crop insurance: generally negative ETE. 	<ul style="list-style-type: none"> • Payments based on crop area provide direct incentive to expand area of production, likely to cause negative EE. • Where support focuses on a specific commodity or sector, overall environmental impacts depend on the environmental outcomes associated with different land uses: if on balance support incentivises a shift towards lower-intensity land uses, overall environmental impacts from support may be positive. Overall assessments need to take into account shifts between agricultural land uses (e.g. pasture versus cropping), and also between agricultural and non-agricultural land uses. • Subsidised crop insurance can incentivise expansion of production on marginal land, and intensification, which likely increases environmental risks; environmental impacts due to fertiliser and chemical use depend on whether these inputs are risk-increasing or risk-decreasing and farmers' risk profile. • Subsidised crop insurance can incentivise risk-taking behaviour and maladaptation in the context of climate change.
C2(b). Payments based on current A/An/R/I, production required—current animal numbers)	<ul style="list-style-type: none"> • Coupled payments: generally negative ETE. 	<ul style="list-style-type: none"> • Direct incentive to expand livestock numbers, likely to cause negative EE. • Positive EE if payment is specifically for less-extensive livestock system. • Where support focuses on a specific commodity or sector, overall environmental impacts depend on the environmental outcomes associated with different land uses: if on balance support incentivises a shift towards lower-intensity land uses, overall environmental impacts from support may be positive. Overall assessments need to take into account shifts between agricultural land uses (e.g. pasture versus cropping), and also between agricultural and non-agricultural land uses.
C2(c). Payments based on current A/An/R/I, production required—agri-environmental schemes (AES) and organic payments	<ul style="list-style-type: none"> • Mixed evidence on ETE; effects depend on AES design and local conditions. • Payments for organic farming: mixed evidence on ETE, but a negative finding is more common. 	<ul style="list-style-type: none"> • Neutral or positive EE depending on scheme design (neutral if scheme is ineffective due to issues such as low additionality, high leakage, poor enforcement, etc.) • Payments for organic farming: generally positive EE per unit of area, which may be offset in per output terms if organic farming also causes lower productivity, which appears to be common.
D. Payments based on non-current A/An/R/I, production required	<ul style="list-style-type: none"> • Limited evidence, showing payments can incentivise increased production above efficient levels; implies a negative ETE. Significance of effect appears to depend on how the payment is set. 	<ul style="list-style-type: none"> • Neutral or slightly negative EE • However, incentive to retain environmentally sensitive land in production may dis-incentivise conservation of these areas and lead to increased environmental risks over time.
E1. Payments based on A/An/R/I, production not required (variable rate)	<ul style="list-style-type: none"> • Generally neutral ETE, since payments typically have a minor impact on agricultural production decisions 	<ul style="list-style-type: none"> • No direct incentive to increase production at intensive or extensive margin, therefore likely neutral or low EE • However, counter-cyclical payments may incentivise keeping environmentally sensitive land in production which may dis-incentivise conservation of these areas and lead to increased environmental risks over time
E2. Payments based on A/An/R/I, production not required (fixed rate)	<ul style="list-style-type: none"> • Decoupled crop area fixed payments: neutral or positive ETE • No clear evidence that introduction of mandatory constraints reduces productivity or efficiency. Mixed evidence on overall economic impacts of mandatory constraints. 	<ul style="list-style-type: none"> • No direct incentive to increase production at intensive or extensive margin, therefore likely neutral or low positive EE • Decoupled payments (especially in conjunction with mandatory conditions requiring minimum land management) can lead to extreme homogenisation of agricultural landscapes, with consequential declines in biodiversity. • Evidence on success of mandatory constraints added to decoupled payments to improve environmental sustainability is not clear.

Policy type	Effect on technical efficiency (ETE) and productivity (EP)	Environmental effects (EE)
F. Payments based on non-commodity criteria	<ul style="list-style-type: none"> • ETE highly dependent on specific payment structure. • Payments incentivising long-term resource retirement can have positive ETE where they incentivise retirement of marginally productive land. 	<ul style="list-style-type: none"> • Positive if payment is for land-use change towards less intensive uses (e.g. payments for afforestation or wetland reconstruction) • Positive if payment is for production of environmental good (e.g. environmental markets)

Agri-environmental policy instruments

23. Table 1.3 provides an overview of findings by agri-environmental instrument type. For instruments except agri-environmental schemes, evidence is drawn from the literature review on impacts of environmental policies in agriculture. For agri-environmental schemes, findings from both literature reviews and the two empirical applications are incorporated.

Table 1.3. Economic and environmental impacts of agri-environmental policy instruments

	Economic impacts	Environmental impacts
Regulatory instruments	<ul style="list-style-type: none"> • Little evidence of significant negative economic impacts of environmental regulations on the agriculture sector in aggregate; some studies even finding a positive impact. • Costs of complying with environmental regulations appear to matter more for smaller farms, and also depend on factors such as the availability of alternatives (e.g. in the context of a ban on specific inputs) and the ability to pass on costs to consumers. • Inefficient use of inputs, particularly fertilisers, is a key source of agricultural pollution. In this context, environmental regulation can create a “win-win” outcome by simultaneously inducing improvements in input use efficiency and reducing pollution. • Some evidence that increased stringency of environmental regulations improves farm technical efficiency. • Final impacts of environmental regulations which decrease crop yields (e.g. pesticide bans) are likely to be less negative than initial impacts as market feedback mechanisms mitigate direct crop revenue impacts. 	<ul style="list-style-type: none"> • Input and technology standards can be highly effective in achieving specified environmental goals, but they need to be set at a level to achieve the goal(s) and require effective enforcement mechanisms. • However, input and technology standards can be inefficient in that they achieve goals at high cost due to preventing flexibility. • Standards can be a better policy option in contexts where environmental risks are higher (e.g. highly vulnerable soils).
Hybrid instruments	<ul style="list-style-type: none"> • Cross-compliance requirements under the EU CAP ^b appear to impact different farm types differently, but in general the economic impacts appear to be neutral or small in magnitude. • Limited evidence on economic impacts of hybrid instruments outside the EU context. 	<ul style="list-style-type: none"> • Cross-compliance requirements under the EU CAP ^b have improved the environmental performance of agriculture but could be made more effective. . • Conservation compliance requirements for the US Farm Bill appear to have contributed to reduced erosion on highly erodible land, and may have forestalled conversion of wetlands for crop production.
Voluntary agri-environmental schemes (AES) for working agricultural lands	<ul style="list-style-type: none"> • Some evidence that providing positive incentives to adopt environmentally sustainable farming practices (e.g. ecological direct payments under the EU CAP ^b) can increase farm technical efficiency, providing a “win-win” outcome. • The evidence on the impacts of participation in voluntary AES on farm profitability is mixed. In some cases, participation in AES is associated with increased yields and profitability, which could be viewed as a “win-win” outcome. However, these positive impacts on profitability may alternatively point to issues such as selection bias, a lack of additionality and the creation of “windfall gains” for participating farmers. 	<ul style="list-style-type: none"> • Environmental effectiveness of AES across OECD countries varies widely. • AES using an “action-oriented” or “pay-for-practice” approach have had mixed success in improving environmental outcomes, and in general have been found to lack cost-effectiveness. • Some early evidence that using “result-oriented” or “pay-for-performance” approaches deliver better environmental outcomes than action-oriented approaches; however, such schemes are not yet widely used and more evidence is needed. • For biodiversity objectives, targeted schemes which focus on the needs and spatial distributions of specific species of interest tend to be more effective than untargeted ones. • When applied to intensively farmed landscapes, AES appear to have the best environmental performance when applied landscapes of simple to intermediate complexity and when tailored to the specific region in which they are being implemented. • Conservation payments can have unintended negative environmental impacts in a context of risk: the payments can induce risk averse farmers to use more fertiliser and pesticides rather than less as they become less focussed on mitigating risk by minimising inputs.

Economic impacts	Environmental impacts
<p>Voluntary agri-environmental schemes (AES) —Land retirement programmes</p>	<ul style="list-style-type: none"> • AES under the EU CAP ^b have in some cases caused extensification of agriculture; a similar effect is observed in the US where EQIP ^a payments may lead to an expansion in irrigated acreage. To the extent that extensification brings land into production that was not previously cultivated, AES could have unintended negative environmental impacts. • AES which pay farmers to retire agricultural land appear to generally have positive results for biodiversity on retired lands, and can also have broader environmental benefits in terms of improved ecosystem functions, although such wider benefits are less studied. However, there is a need to consider such programmes holistically and account for the potential for intensification on remaining working land, as well as to ensure retired land is appropriately managed (i.e. avoid negative environmental outcomes which can be associated with land abandonment).
<p>Public investment in water-saving irrigation technology</p>	<ul style="list-style-type: none"> • Publicly-funded investment in improving the efficiency of agricultural irrigation infrastructure can induce structural change, with farmers adjusting towards higher-value crops. While studies found infrastructure upgrades have increased productivity of irrigated agriculture, higher electricity costs may offset productivity gains. • Investment in water-saving technology (e.g. irrigation infrastructure efficiency upgrades) has generally increased the productivity of affected farmers in terms of water use (diversions) per unit of agricultural production. However, the overall effect on the environmental performance of agriculture depends on factors such as changes in return flows, whether productivity increases stimulate increased irrigated area (i.e. expansion on the intensive margin), changes on the intensive margin, or change of crop type.
<p>Environmental taxes and charges</p>	<ul style="list-style-type: none"> • In general, very high taxes are needed to induce reductions in fertiliser use to environmentally-sound levels, due to low own-price elasticity for fertiliser inputs. This implies that imposition of taxes set at a level needed to achieve environmental objectives could have strong negative economic impacts for farmers. • Limited ex post evidence on economic impacts of environmental taxes and charges in agriculture. • Input taxes (e.g. nitrogen taxes) appear to be an inefficient mechanism for (water) pollution control: in general, very high taxes are needed to induce reductions in fertiliser use to environmentally-sound levels, and they therefore have a higher impact on farm profits than nutrient input restrictions. • Emissions taxes appear to be the first-best instrument for addressing nutrient emissions from agriculture, however they may be difficult to implement in practice due to difficulties in tracking non-point source emissions. • Input taxes appear to be more efficient than water pricing mechanisms (taxes on irrigation water) for addressing water pollution issues. • The relative performance of input standards and input taxes in achieving environmental objectives may depend on soil type. • Water taxes or tariffs are not often used to manage water scarcity for agriculture, but are used in some cases to recover costs of water irrigation infrastructure. Water pricing appears to be an inefficient mechanism for (water) pollution control.
<p>Environmental markets (tradeable allowances)</p>	<ul style="list-style-type: none"> • Water markets provide incentive for agricultural and other water users to adapt and improve their productivity (water use efficiency). • Water markets have been shown to deliver significant benefits for agriculture, particularly in dry years, and particularly in relation to highly-developed water markets such as those in the Australian southern connected Murray-Darling Basin. • Limited evidence is available on the impacts of other market mechanisms (e.g. biodiversity offsets) on economic performance. • Well-functioning water markets have been shown to be an effective mechanism to manage consumptive water use, but may need to be used in conjunction with reallocation mechanisms (for example, regulations on minimum environmental flows, “buyback” mechanism to purchase water for the environment) in order to address over-allocation issues. Potential for (unintended) negative environmental impacts (e.g. changes in return flows and dilution flows, activation of previously-unused water access rights) needs to be addressed. • There is limited quantitative information available on the environmental outcomes of biodiversity offset markets.

Note: AES = agri-environmental schemes. a EQIP = Environmental Quality Incentives Program (USA). b EU CAP = European Union Common Agricultural Policy.

Do agri-environmental policies inherently involve a trade-off between productivity and sustainability?

24. At the farm level, the empirical literature does not establish a simple relationship between environmental performance and economic performance in agriculture. It does however identify a number of factors that positively (or at least non-negatively) impact this link (i.e. increase the likelihood of a positive relationship between environmental and economic performance). These include: farm size, presence of demand for environmentally-differentiated goods, and the ability to respond “proactively” to external pressures to improve environmental performance; that is, to voluntarily change production processes towards being more environmentally sustainable in anticipation of external factors such as regulation or changing demand, or to accept change (especially regulatory change) rather than resisting it. This finding suggests that policies should be designed with such pre-existing relationships in mind: for example, policy-makers could couple introduction of new regulations with innovation policies targeted at helping farmers to comply, or with a consumer-side policy aimed to stimulate demand for environmentally sustainable products.

25. The limited available evidence suggests the productivity impacts of agri-environmental regulations are mixed. Importantly, there are several cases identified where regulations can have *positive* effects on productivity, at the same time as improving environmental performance; i.e. a “win-win” outcome for sustainable productivity. One important pathway via which this occurs – known as the Porter Hypothesis – is that regulation can spur innovation that ultimately provide economic benefits which outweigh compliance costs.

26. Existing examples of hybrid instruments (e.g. environmental cross-compliance) show generally that they do not have statistically significant impacts on participating farms’ productivity. Where impacts do occur, they can be positive or negative but are generally small in magnitude. When coupled with the evidence that such instruments have typically been unsuccessful in substantially improving environmental performance (partly because environmental requirements have not been sufficient), the conclusion reached is that, while such mechanisms appear promising in theory, in practice they have yet to be successful at stimulating real change.

27. There is little evidence that economic agri-environmental policy instruments (AES, market-based approaches) negatively impact participating farmers’ economic performance. This is in line with economic theory, which posits that, since these mechanisms are voluntary, a rational profit-maximising farmer would not enter if they expected their economic performance to suffer. Nevertheless, there are some isolated cases where voluntary mechanisms do appear to have had a negative impact on participating farmers’ productivity or economic performance more generally; these cases can provide lessons for policy-makers on what to avoid. Given the evidence of limited success to date on achieving environmental effectiveness (and cost-effectiveness), it appears that these mechanisms have room for improvement but may be capable of delivering “win-win” outcomes for both environmental and economic performance of agriculture, although challenges such as mitigating selection bias and ensuring additionality remain.

28. The possibility that policy impacts differ with and without (or before and after) innovation means that the long-term impact of policies may differ from short-term impacts and that “win-win” outcomes may only occur over time (i.e. lagged effect). Innovation, particularly the ability for a farm to respond to external stimuli, has been found to be one

of the factors determining whether regulations positively or negatively impact economic performance. Stimulating innovation can also be key to the design of successful policy instruments. For example, results-oriented mechanisms are considered to have the potential to stimulate on-farm innovation and adaptation of environmental management practices to local conditions, and thereby achieve lasting improvements in agricultural environmental sustainability. However, empirical evidence on the degree to which results-oriented mechanisms actually spur innovation is scant, not least because results-oriented mechanisms are still in their infancy. Further, there are many definitions of exactly what constitutes a result-oriented mechanism. Nevertheless, there is much optimism that result-oriented measures will be both more effective and more efficient than practice-based mechanisms. Additional work in this area is needed to clearly define the spectrum of different payment structures and consider which type(s) of payments are optimal under which conditions.

Limited effectiveness of “beneficiary pays” mechanisms may be a source of trade-offs between productivity and environmental sustainability

29. The literature identifies an area for significant “room for improvement” in both the effectiveness of agri-environmental policies for improving agriculture’s environmental performance and their economic efficiency, particularly in relation to existing hybrid instruments (e.g. cross-compliance) and voluntary agri-environmental schemes (AES). While there was considerable heterogeneity found across different contexts, in general action-oriented (also called practice-based) measures often performed poorly on effectiveness and efficiency criteria. Site-specific economic and biological conditions cause substantial heterogeneity in the environmental effectiveness and cost-effectiveness of agri-environmental policies; therefore, policies need to be targeted to specific conditions and should take into account bio-physical relationships, farmer decision-making and broader economic relationships. Where agri-environmental policies do *not* succeed in substantively improving environmental performance, there is a real risk that rather than creating a “win-win”, unintended outcomes could occur. For example, the policy could be spending public funds for very little tangible benefit and inappropriately subsidising economic performance; alternatively, the policy may be funding insignificant gains in environmental performance but causing significant *decreases* in economic performance, such that the benefits are far outweighed by the costs.

Taking a more holistic view: evidence on impacts of policy packages and long-term impacts

Long-term impacts of decoupling agricultural support from production

30. When high levels of support are maintained over time, structural change may be impeded in the agriculture sector. Further, if support remains coupled to production, innovation (e.g. to produce higher yield varieties) could be biased in favour of particular crop types or production methods receiving the most support. At the same time, support may be capitalised into land values which may enhance underlying pressures for farm consolidation and intensification (OECD, 2005^[23]) and may reduce producers’ ability to make productivity-enhancing or environmentally-friendly investments in a context where higher land prices result in increased farm debt.

31. Policy reform (e.g. decoupling) may cause long-term structural effects such as farm entry or exit, changing farm size (e.g. consolidation), and introducing new options for

production mix (i.e. policy reform might not only cause substitution between existing crop or livestock types, but allow for new products to be produced or new production methods to be used).

32. Some authors find that decoupled direct payments slow the pace of structural change. The “desirability” of this effect depends on local context. For highly productive areas, retarding structural change may slow productivity growth and act as a barrier to further economic development. However, in marginal areas, it may lead to avoiding the abandonment of agricultural land and the maintenance of landscapes that are valuable for biodiversity, tourism and the maintenance of rural communities.

33. In the QCA analysis, pathways for environmental sustainability outcomes appear to be mainly driven by production structure and intensity related conditions and less so by contemporaneous agricultural support policies. Overall, the QCA analysis shows that, for the cases studied, the only countries to achieve a high level of ‘strong sustainability’ were those with a certain type of production structure (low livestock density and thus manure intensity) *and* a low level of distorting agricultural policies (PSE categories A, B and C). These results imply that decoupling of agricultural support may not solve environmental problems related to production structure and intensity in cases where structures and intensities are high due to past policies and due to current price ratios provided by markets. Naturally, decoupling removes intensification incentives provided by production enhancing policies, but it does not incentivise *lower* intensity than price ratios given by markets. Thus, in countries with certain production structures and production intensity, both reduction of distorting policies (PSE category A, B and C payments) *and* adding strong environmental cross-compliance criteria to category D and E payments may be warranted in order to minimise harmful environmental impacts of agricultural support policies.

Long-term impacts of removing agricultural support

34. The literature review on long-term impacts of removing agricultural support, using evidence from the Australia and New Zealand experience. This evidence shows that in these cases, removal of support had the following impacts:

- In New Zealand, removal of support removed incentives to bring new land into production, and motivated a strong shift out of sheep into dairy, forestry, wine and deer production. Over the long-term, agricultural productivity growth has risen due to these reforms. Environmental impacts have been both positive and negative.
- In Australia, removal of market price support for dairy has led to rationalisation of the industry, resulting in fewer farms with larger herds and efficient production systems. Environmental impacts of deregulation are less clear: Australian dairy production systems have been trending towards increased intensification both before and after the reform, but environmental impacts (specifically, increasing nutrient concentrations in streams in dairying regions) have not increased as strongly in the post-reform period.

Conclusions and policy recommendations

35. Based on the evidence presented above and in the supporting analyses, this section provides conclusions and recommendations for policy-makers.

36. Environmental impacts in terms of nutrient and greenhouse gas emissions are driven by net changes in intensity of agricultural production systems, which in turn is comprised of farmer decision-making at the intensive, extensive and entry-exit margins. Different agricultural support instruments affect choices at these different margins differently. While exceptions may occur in particular contexts, the overall findings from the literature reviews and two empirical analyses are the following:

- Market price support, payments based on outputs, and payments based on unconstrained variable input use generally have negative impacts on environmental outcomes unless they incentivise shifts towards lower-intensity land uses.
- **Market price support, payments based on output and payments based on variable inputs** affect incentives at all three margins. If these payments incentivise shifts towards higher intensity land uses at the extensive margin, the overall result is increased environmental pressures, as all incentive effects operate in the same direction.

However, given that these payments (apart from payments with input constraints or payments based on ‘environmentally friendly inputs’⁹) incentivise increased intensity at the intensive margin (i.e. incentive to increase yields), if payments incentivise shifts towards relatively *lower* intensity land uses at the extensive margin, the overall effect will depend on whether the intensity effect via the intensive margin dominates the intensity effect on the extensive margin. In these cases, environmental impacts are an empirical matter and depend on how the relative emission intensity differs between different land uses, for example croplands versus grasslands.

- **Payments based on current area or animal numbers** affect environmental pressures via the extensive and entry-exit margins. Therefore, they could have environmentally positive impacts only if they support shifts towards land uses with relatively lower intensity. In order to incentivise such land use shifts, these payments would need to alter the relative profitability of low-intensity land uses (e.g. pasture) relative to higher intensity land-uses (e.g. annual crops).
- **Decoupled payments** generally do not affect incentives at the intensive or extensive margin, but may affect incentives at the entry-exit margin, specifically, via dampening incentives to exit via bolstering profitability of agricultural activities relative to other land uses (e.g. forestry). Decoupled payments accompanied by mandatory constraints related to maintaining agricultural lands may also incentivise farmers to retain agriculture-related land uses (e.g. fallow, meadows, pastures) rather than converting to alternative land-uses.¹⁰

37. It should be noted that this study employs the OECD Producer Support Estimate (PSE) classification of agricultural support policies. It is acknowledged that the PSE classification has some drawbacks when analysing environmental impacts of policies, in

⁹ Examples of environmentally friendly inputs are conservation practices such as conservation tillage, or fertilisers specifically designed to help minimise nutrient losses to the environment.

¹⁰ Note that in the case of mandatory constraints, it is the combination of the policy components (i.e. payment plus constraint) that may affect the entry-exit margin, rather than the payment alone. When payments are decoupled (i.e. payment basis is not related to current production) but are accompanied by production-related constraints, the combined instrument may in practice meet the strict definition of being fully decoupled.

that the PSE categories and labels do not distinguish between different kinds of constraints or other policy design features which could be expected to have different environmental impacts. Thus, in order to evaluate specific policies, it would be important to have more information on the nature of constraints, for example, for an input constraint, the type of input being constrained and the level of the constraint.

38. In the farm-level modelling application, extensive margin impacts seem to dominate. Although some agricultural support policies do affect intensive margin decisions (such as fertiliser application intensity and livestock feeding), environmental effects in terms of nutrient and greenhouse gas emissions seem to be primarily driven by extensive margin decisions (shifting between different types of agricultural land uses). These results are consistent with those obtained in another recent OECD *ex ante* modelling study (Henderson and Lankoski, 2019^[24]).

39. In the QCA analysis, pathways leading to poor or good environmental outcomes are dominated by existing nutrient intensities, which reflect industry structure and the effects of past policies. In comparison, the impacts of contemporaneous policy settings seem more muted. This outcome appears to be stronger in relation to greenhouse gas emissions than nutrient emissions. These results point to the importance of long-term factors: changes affecting nutrient balances (especially for phosphorus) may take more time to occur than changes affecting greenhouse gas emissions. Output and input payments affect both the intensive and extensive margins, whereas payments based on current area or animal numbers affect only the extensive margin. For annual cropping systems, these effects are likely to occur over the short term, as farmers can immediately respond on both the intensive and extensive margins. For livestock systems, impacts, particularly on the extensive margin, may take longer to occur, due to the costly investments needed to expand livestock operations.

40. Environmental impacts in terms of biodiversity appear to be driven by changes to overall landscape structure and quality, and impacts may differ for different species. Policies which incentivise homogenisation of land use are generally negative for biodiversity. Thus, biodiversity impacts also appear to depend heavily on decisions at the extensive and entry-exit margins. This is not to say that intensive margin decisions are not important for biodiversity; pesticide and nutrient decisions can have important impacts, especially at the edge-of-field or local level, via their impacts on field margin habitats and adjacent or receiving water bodies. However, the majority of studies considering agricultural policy impacts on biodiversity use habitat-based indicators, which reflect more closely land-use changes.

Production-related support performs poorly with respect to productivity and environmental sustainability perspectives

41. The evidence suggests that support coupled to production¹¹ (e.g. payments based on outputs) generally has a negative impact on farm technical efficiency and productivity, as well as negative environmental impacts, especially on highly productive land. The magnitude of both productivity and environmental impacts can differ across different contexts (see the literature review on the impacts of agricultural policies on productivity

¹¹ The majority of studies examining impact of coupled support do not identify whether payments are made based on output (PSE Category A2) or current receipts, income, area or animal numbers (PSE Category C). However, the latter kind of payments are more dominant in OECD agricultural support measures.

and environmental outcomes in agriculture for a discussion (DeBoe, 2020_[4]). Given that coupled payments most often cannot be easily differentiated between more and less productive land types or other conditions, there appears to be no clear rationale from a sustainable productivity perspective for maintaining these kinds of payments.

42. There is also strong evidence of a negative relationship between farm dependency on support and technical efficiency. This raises questions about the suitability of using agricultural support payments to significantly supplement farm incomes, as it suggests there may be a trade-off between productivity (including technical efficiency) objectives and other objectives related to supporting farm incomes.

Decoupling agricultural support from production removes distortionary incentives for intensification, but does not internalise negative environmental externalities of agricultural production

43. Past policies and other factors have in several contexts produced agricultural production systems which are highly intensive, and which have high negative environmental impacts, particularly in terms of nutrient runoff and greenhouse gas emissions. Many governments have recognised the negative environmental impacts of coupled forms of support, and have at least partly decoupled agricultural support from farm production decisions. Evidence indicates that decoupling successfully removes distortionary intensification incentives provided by coupled support and payments based on inputs, and, as intended, allows farmers to respond to and benefit from incentives provided by the market. However, given that prices in agricultural input and output markets do not take into account environmental (or other) externalities associated with agricultural production, market forces cannot be relied on to incentivise a shift towards *lower* intensity (and environmental impacts). Thus, decoupling on its own is unlikely to solve environmental problems related to production structures and intensity in cases where structures are sub-optimal from an environmental perspective and intensities are high due to past policies and due to current price ratios provided by markets. Therefore, in countries with certain production structures and production intensity, both reduction of PSE category A, B and C payments *and* adding strong environmental cross-compliance criteria to category D and E payments is needed in order to minimise harmful environmental impacts of agricultural support policies.

Better policies are needed to prevent and address land-use homogenisation and land abandonment, and to address landscape-scale environmental issues

44. While policy reform can successfully reduce incentives to intensify agricultural production, reforms which incentivise extreme land use homogenisation or significant land abandonment—as opposed to conversion of land to other managed land uses¹²—can have major negative environmental consequences, particularly for biodiversity, but also for soil quality in areas prone to erosion or salinity. Moreover, moving towards lower-intensity production systems may require different land use configurations, even in some cases requiring expansion of agricultural lands. Policy-makers therefore need to take a more

¹² Here, the analysis distinguishes between ‘land abandonment’, in which agricultural land contraction is not actively managed but left to ‘passively’ re-wild; compared to ‘land retirement’ in which agricultural land uses are intentionally replaced by other land uses. This could include actively managing conversion of land toward a more natural state (‘active re-wilding’).

holistic approach and consider how individual policy instruments interact and what their impacts are at a landscape level.

45. Many researchers identify mandatory constraints (e.g. cross-compliance) and agri-environmental schemes as policy tools that have high potential to improve the sustainability of agriculture. However, the evidence shows limited success of existing mandatory constraints to mitigate negative environmental impacts, or the ability of agri-environmental schemes to incentivise production of agri-environmental goods and services, with many existing examples found to be of limited environmental effectiveness. This suggests that the design of mandatory constraints and agri-environmental schemes could be improved to deliver better environmental performance without sacrificing economic performance.

46. Another way of framing these two dimensions is that, in general, recent reforms have focussed on mitigating the negative environmental impacts (“environmental bads”) of existing distortionary policies; there is also a need for further policy developments focussing on *increasing* the production of environmental and other public goods (e.g. cultural goods) from agriculture. The literature review of environmental policies for agriculture and the farm-level modelling (Chapter 2) both indicate that environmental payments (including payment for ecosystems services approaches and environmental markets) have potential to incentivise increased production of public goods by the agriculture sector. However, evidence on success for existing programmes is patchy, as design flaws and implementation problems abound (see literature review for a detailed discussion (OECD, 2019_[31])).

Environmental regulations can play a positive role in the policy mix, and do not necessarily involve a trade-off between productivity and environmental objectives

47. Few studies assess the productivity impacts of agri-environmental regulations, and available evidence suggests that these impacts are mixed. Importantly, however, there are several cases identified where agri-environmental regulations can have *positive* effects on productivity, at the same time as improving environmental performance. One important pathway via which this occurs—known as the Porter Hypothesis (PH)—is that regulation can spur innovation that ultimately provides economic benefits which outweigh compliance costs. The limited available evidence from the agriculture sector is supported by evidence from other sectors, which also shows that regulations can in some cases have a positive effect on productivity.

48. Agri-food regulations (e.g. nutrition regulation, food processing standards, etc.) can also play a role in assuaging consumer food safety concerns, “suspicion” towards new food products, and also play a role in providing trusted information about characteristics of agricultural commodities which consumers are unable to observe directly (e.g. information on environmental impacts of production methods). Thus, regulations can affect the benefits of innovation and ultimately farm performance not only via acting directly on the farm, but also via their effects on consumer demand. Further, where ‘green technology’ displays public good characteristics or has positive externalities, regulations can be a tool to help agricultural actors co-ordinate to produce a socially optimal outcome.

49. While economics generally recommends use of market-based instruments to address environmental problems in agriculture on efficiency grounds, regulations can play a positive role in the policy mix. Evidence from studies examining the impacts of alternative policy instruments for addressing nutrient emissions from agriculture shows that where input elasticities are low (e.g. demand for fertiliser does not change significantly in

response to price fluctuations), regulations such as nutrient standards may perform better than economic instruments such as nutrient taxes, because in this context taxes need to be set very high to achieve any real change. Also, agri-environmental regulations are often successfully used in contexts where there are threshold effects (e.g. in relation to toxic chemicals).

Recommendations on advancing the evidence base: where to from here?

50. This report provides an overview of existing evidence on the impacts of agricultural support instruments and agri-environmental policy instruments on environmental sustainability and productivity performance in agriculture. However, some gaps remain and this section provides some recommendations on advancing the evidence base.

More research is needed which clearly identifies key instrument features

51. Many studies which estimate technical efficiency impacts of agricultural support policies do not contain much information about the payment type, analyse aggregated categories such as “coupled payments” or “total subsidies” which amalgamate a number of different payment types, or use terms such as “direct payments” whose meaning is not necessarily clear and could change over time. There is a need for more work that isolates the individual impact of specific policy instruments.

52. Similarly, there is a need to distinguish between policies with accompanying mandatory conditions and those without, as well as the type of condition—this is particularly crucial in relation to environmental conditions. The OECD (2016_[20]) has previously noted that the OECD PSE categorisation has some limitations when being used for evaluating agri-environmental policies;¹³ one particular improvement would be to include a higher level of detail about the nature of constraints (e.g. for an input constraint, the type of input being constrained and the level of the constraint), particularly to be able to distinguish between payments based on inputs which are environmentally helpful versus those which are harmful.

More holistic analytical approaches are needed to explore synergies and trade-offs between instrument types and between productivity and environmental sustainability objectives

53. There is a need for more studies to consider both economic and environmental impacts at once, in order to gain more evidence on the potential for complementarities or trade-offs between productivity and environmental sustainability objectives. While a piecemeal approach of gathering evidence across many different studies (as has been done in the two literature reviews on which this report is based) yields useful insights, theoretical and empirical approaches differ so greatly across studies that it can be difficult to “link up”

¹³ OECD (2016, p. 189_[20]) states: “the [PSE] indicator database in its current version does not lend itself to modelling agri-environmental policies. These policies are characterized by an “input constraint” label, indicating whether the input constraint is voluntary, and whether it has an environmental objective. However, these same policies can be classified under categories B through to F depending on the implementation criteria for provision. Even if the modeller knows that a programme is agri-environmental, the input constraint label provides no information on the type of input being constrained and on the level of constraint. Consequently, the analyst cannot distinguish between a policy limiting the stocking rate on pasture and one limiting fertiliser use.”

environmental results from one study with economic results from another to have a holistic assessment.

54. The ability to jointly analyse environmental and productivity impacts also requires improvements in methodologies for producing joint indicators, such as ‘sustainable productivity’ or ‘environmentally-adjusted total factor productivity’ indicators. Another aspect to consider is the empirical methods used to evaluate policy impacts. The most commonly-used empirical methods used are regression, scenario modelling and stochastic frontier approaches (for technical efficiency analyses). Colen et al. (2016^[25]) note that the use of economic experiments could also provide assistance to evidence-based policy making in the context of the European Union Common Agricultural Policy. Another approach, trialled in this report, is using Qualitative Comparative Analysis (QCA) to analyse complex relationships between government policies and productivity and sustainability performance. The merits of this approach are (i) that it is an *ex post* approach based on observed data; and (ii) that it allows consideration of complex causal relationships, which are fundamental to agricultural policy-making. To provide increased explanatory power, this methodology would require more quantitative data on variables on ‘remote conditions’ such as other policies (e.g. innovation policies) which affect sustainable productivity outcomes in agriculture than was available for the present analysis.

The ability to deliver precise policy advice depends on high quality data

55. In some cases, the ability to undertake policy-relevant analysis is limited by the data upon which analyses are based. A significant case in point is the EU’s Farm Accountancy Data Network (FADN) database.¹⁴ Many of the studies which form the basis of the literature review on impacts of agricultural support instruments relied on FADN data. This database, while providing information on a variety of support categories, does not provide detail on whether constraints are applied, and it is not clear exactly what type of payments are included in some aggregate classes—e.g. the category “environmental subsidies”. Moreover, notwithstanding the recent FLINT initiative¹⁵ to extend the coverage of FADN on environmental variables, this database does not include much detail on farm environmental performance. Thus, studies based on this database are necessarily limited in the level of policy granularity they are able to achieve and in their ability to link policy impacts to economic and environmental outcomes.¹⁶ More generally, more granular data is needed (i.e. higher spatial resolution) to fully examine the environmental impacts of agricultural and agri-environmental policies.

56. The OECD supports countries’ efforts to improve agricultural and agri-environmental data collection and accessibility, for example through the OECD Farm Level Analysis Network¹⁷ and in working together with countries to develop and publish agri-

¹⁴ See <http://ec.europa.eu/agriculture/rica/>, accessed August 2018.

¹⁵ See <http://www.flint-fp7.eu/Results.html>, accessed August 2018.

¹⁶ Additionally in many countries, FADN does not all the environmental indicators needed to evaluate policies. In this case, the FADN survey is combined with other surveys that contain this information. A further issue is the granularity, i.e. that the farm level collected in FADN datasets is not sufficiently granular for some environmental issues. Another issue is the lack of panel data in some countries.

¹⁷ See <https://www.oecd.org/agriculture/farm-level-analysis-network/>, accessed August 2018.

environmental indicators¹⁸ that are relevant for policy analysis and comparable across countries. However, more work is needed to improve the granularity and coverage of data for policy-relevant research, and to improve access to existing government-held datasets (OECD, 2019^[26]). Further, more engagement between policymakers and researchers is needed to ensure academic studies yield results that are directly relevant to policy-making.

Further work is needed to evaluate the environmental impacts of agri-environmental instruments

57. There are several ways in which future work could improve the evidence base in relation to assessing the *environmental impacts* of agri-environmental policies. There are some important limitations of existing research into the cost-effectiveness of agri-environmental policies, including:

- Assessments may be based on ‘representative’ farm types and as such may fail to capture the inherent heterogeneity across farms.
- assessments may concentrate on the effect of a single measure and therefore fail to account for interactions between different instruments that form part of a ‘policy package’.
- assessments may not sufficiently take into account uncertainties in both costs and environmental effects estimates.
- assessments may focus on one particular environmental performance variable, while ignoring others.

58. Baylis et al. (2016^[27]) note a number of practical difficulties which seriously impede robust impact evaluation for agri-environmental policies: policies having multiple outcomes or multiple scales; spatial spill-overs (leakage); failure to account for confounding factors; the limits of practically implementing randomised control trials in an agricultural context, and the small scale of many agri-environmental initiatives. Also, too often attempts to assess policy effectiveness are based on measures of participation rather than ecological effectiveness. In many cases, there is a lack of suitable indicators to assess the environmental effectiveness of agri-environmental policies, as well as a range of methodological issues such as time lags, disentangling the effects of multiple policy and market effects, etc.

59. Some aspects of the policy design itself make evaluation of effectiveness difficult. Too often, the vague specification of policy objectives frustrates any attempt to assess the extent to which those objectives are achieved. Also, policy evaluations are often unstructured, and environmental outcomes of agri-environmental policies are insufficiently documented. Thus, policy-makers and administrators have a role to play in designing policies that are able to be effectively evaluated, particularly in relation to setting measurable policy objectives and conducting methodical evaluations.

¹⁸ See <http://www.oecd.org/tad/sustainable-agriculture/agri-environmentalindicators.htm>, accessed August 2018.

Part II: Empirical studies on linkages between agricultural policies, productivity and environmental sustainability in agriculture

Part II comprises two empirical applications examining the productivity and environmental sustainability impacts of agricultural policies.

Chapter 2 presents an *ex ante* farm-level modelling analysis, which isolates the impacts of specific agricultural support payment types, drawn from the OECD Producer Support Estimates (PSE) classification.

Chapter 3 analyses complex causal relationships between agricultural policies and productivity and sustainability performance in agriculture, using an *ex post* methodology known as 'Fuzzy Set Qualitative Comparative Analysis' (QCA).

Annexes A to E provide additional technical information on the modelling approaches used in Chapters 2 and 3.

2. A detailed look at productivity and sustainability impacts of selected agricultural support instruments using farm-level bio-economic modelling

Introduction

60. This chapter contains the results of quantitative modelling for assessing the impacts of agricultural support policies on environmental sustainability and sustainable productivity in agriculture. It focuses on the main categories of agricultural support policies based on the OECD Producer Support Estimate (PSE) classification and examines the support measures that are likely most relevant to environmental sustainability and sustainable productivity performance.

61. The bio-economic farm model employed in this application was developed in Henderson and Lankoski (2019^[24]). For this application the model structure has been revised to allow application of the model to a wider range of agricultural production systems across the OECD member countries to facilitate the model's parameterisation to various country situations. Another important development has been to develop a code, which calibrates the model against observed crop and milk yields, acreage and herd size and nitrogen fertiliser use. Here, Positive Mathematical Programming (PMP) was used as a key element.

62. The new model structure is tested with data of the CAPRI database for the year 2012, considering 23 European countries. The aim is to derive stylised regional production systems based on regional data on, for example, crop acreage and dairy cow numbers, crop and milk yields, application of nitrogen and phosphorus in chemical fertiliser and manure, feed inputs, value of outputs and production inputs, and various GHG emissions and total global warming potential of crop and milk production. A clustering approach is adopted which allows data to be grouped on the basis of similarity across production technologies on the basis of a set of agricultural production data from the CAPRI database. The aim is to generate a robust grouping of regions based on production technologies.

63. The chapter is organised as follows. Section 2 provides a brief description of the bio-economic farm model. Section 3 presents data, clustering approach and model calibration. The results are provided in Section 4, while Section 5 concludes.

Model specification

64. This section provides a brief description of the bio-economic farm model employed for the analysis. A more detailed description can be found in Henderson and Lankoski (2019^[24]).

65. The bio-economic farm model accounts for the interactions between decisions on livestock (milk production) and crop choices associated with: (i) on-farm fodder production, (ii) manure use as a source of nutrients, and (iii) competition for quasi-fixed resources such as land and labour between crop and dairy production. The baseline case of the model depicts interrelated profit maximal choices of the herd size, milk and crop yields, diet, fertilisation and land allocation between grass silage, pasture and crop production under current market and policy conditions. Under different agricultural policy instruments, the farmer adjusts decision variables to reach new profit-maximising levels. The model can

be calibrated and solved as a pure crop production model, so that it can be applied in regions that are dominated by crop production.

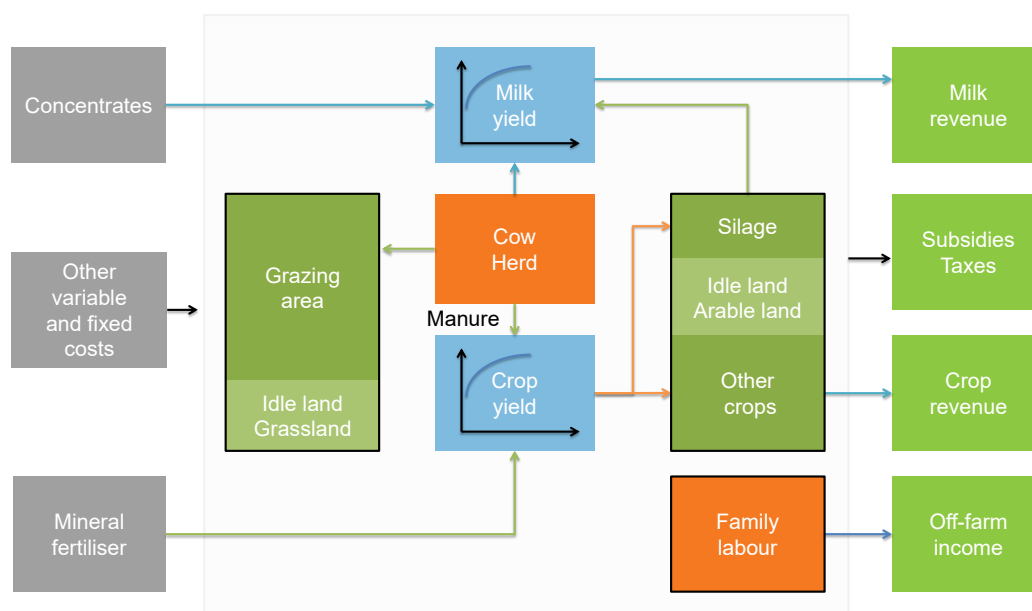
66. For dairy production, the impacts of diet composition on milk yield, manure excretion and manure composition are modelled. Increased intake of concentrates increases milk yield per cow, at a decreasing rate up to a maximal yield level, while in parallel, the intake of fodder decreases. Fodder sources include grass silage produced on-farm and grazing. The replacement of animals for the milk herd is based on heifers raised on the farm. The number of lactations is modelled as a function of the milk yield. All other revenues and costs are expressed as per dairy cow.

67. Fodder and other crops compete for arable land; their yields depend on the applied fertiliser. Mineral fertiliser and manure - reflecting plant-available nutrients - are assumed perfect substitutes. The marginal crop yield response decreases with increasing fertiliser application rates, up to a maximal crop yield. All activities compete for farm labour, which can alternatively be employed off-farm at a given reservation wage. As grass silage is not marketed, its costs reflect, besides production costs, the opportunity costs of labour and land on the one hand and the substitution value against feed concentrates on the other. Similarly, the value of manure reflects differences in application costs relative to mineral fertiliser and the content of plant-available nutrients.

68. A non-linear programming approach is used to implement the bio-economic processes depicted above. It simulates optimal decision making of a farmer (Figure 2.1) under different endowments and technology, as well as market and policy environments. The farmer manages three fixed production factors, indicated by the black-outlined boxes: grasslands, arable lands and family labour; the latter may be used on- or off-farm. The interdependent and simultaneously determined decision variables in the comparative-static framework are the cowherd and acreages, crop and milk yields, mineral and organic fertilisation levels, and the feed mix. The costs of mineral fertiliser and concentrates are explicitly considered as well as other production costs. Revenues stem from selling milk and arable crops; costs for animal replacement and revenues from selling old cows are accounted for as well. Besides grassland and grass silage, the model considers the arable crops wheat, barley and rape. Input and output prices are exogenous.

69. Crop yields are endogenously depicted by nitrogen dependent yield functions of either the Mitcherlich or quadratic functional form. The different crops, including grass silage and pasture, compete for arable land. The model maximises either profits or utility when production risks for crops are considered. Compared to other bio-economic models, this model differentiates itself by employing non-linear crop and milk yield functions and by its endogenous use of IPCC Tier 3 GHG emission accounting.

Figure 2.1. Main interactions in bio-economic modelling framework



Source: Authors.

Model accounting of environmental impacts

70. The following GHG emissions are accounted for: 1) methane emissions from enteric fermentation and from manure storage; 2) direct N₂O emissions from manure storage; 3) indirect N₂O emissions from manure storage and spreading (NH₃ emissions from manure storage and spreading cause indirect N₂O emissions); 4) GHG emissions from cultivated land, including nitrogen fertiliser use and autonomous soil emissions; and 5) emissions from cultivation practices, crop yield transportation and grain drying. Furthermore, soil carbon sequestration is taken into account when arable land is put under green set-aside.

71. Methane emissions from enteric fermentation per cow reflect milk yields and the digestibility of the cow's diet. Methane and nitrous oxide emissions from manure storage depend on feeding and manure storage technologies (e.g. not covered manure storage and manure storage with floating cover).

72. Water quality impacts of agricultural policies are assessed through nitrogen and phosphorus runoff from field parcels to watercourses. Nitrogen runoff mainly depends on nitrogen application rates (both chemical fertiliser and manure) and land cover type, so that cultivated cropland has higher propensity to runoff than grass silage or pasture land. Dissolved phosphorus runoff mainly depends on phosphorus application rates, level of soil phosphorus, runoff volume and land cover type. The runoff of particulate phosphorus is dependent on phosphorus application, soil erosion, amount of potentially bioavailable phosphorus in eroded soil material and land cover type.

Model accounting of productivity impacts

73. This modelling uses two different approaches to assess productivity impacts of alternative policy scenarios.

74. In the first approach, a Divisia index is used to calculate outputs and inputs in each policy scenario relative to the reference scenario and the outputs are divided by inputs to obtain results on relative productivity levels for policy measures. Under this approach, results for productivity do not directly account for environmental impacts. This approach reflects the general approach to defining productivity that is usually taken in studies examining policy impacts on agricultural productivity.

75. The second approach uses a sustainable productivity index, in which environmental effects are considered as factor inputs that add to the social cost of production. Thus, the sustainable productivity index is defined as the ratio between produced output quantity and input quantity, in which GHG emissions and nutrient runoff are on the input side as they represent use of the natural resources and other environmental services.¹⁹ **Annex A** provides a more detailed description of how the Divisia index and sustainable productivity index are defined and calculated. This approach allows joint consideration of productivity and sustainability impacts of policy instruments.

76. This second approach has not previously been often used in the literature; the application here represents an attempt in implementing such a joint approach. While the notion of constructing an indicator which jointly reflects sustainability and productivity elements is appealing to many researchers and policy-makers, assembling the required data can be difficult, and there is a lack of agreement on exactly how such an index should be defined. Nevertheless, this analysis explores the usefulness of this approach and provides preliminary findings, which could help motivate future efforts to develop an agreed methodology for sustainable productivity indicators.

Data, clustering approach and model calibration

77. The model application draws on the database of the Common Agricultural Policy Regional Impact (CAPRI) model (www.capri-model.org/docs/capri_documentation.pdf). CAPRI as an agricultural sector model combines a global partial equilibrium model for agri-food products (employing the Armington assumption to depict bilateral trade) with non-linear programming models for 280 NUTS2 regions or about 3 000 farm group models to detail agricultural production decisions in the European Union, EU candidate countries and Norway. Eurostat is the key data source for the European part of the model providing, for instance, crop and animal production statistics, land use statistics, market balances and Economic Accounts for Agriculture (EAA). The CAPRI database at the national level integrates the EAA (valued output and input use) with, for instance, market balances, trade and production statistics. The country data are subsequently used to derive a regionalised database at NUTS2 level that depicts the allocation of inputs across activities and regions as well as regional acreages, dairy cow numbers, and crop and milk production. The regional data are subsequently further disaggregated to farm type level mainly based on farm structural data.

78. In order to derive stylised regional production systems for the bio-economic model, data from the CAPRI database for the year 2012 is employed, considering 23 European countries. Data relate to, for example, regional crop acreage and dairy cow numbers, crop and milk yields, application of nitrogen and phosphorus in chemical fertiliser and manure,

¹⁹ It should be noted that the sustainable productivity index used in the analysis focuses only on a subset of agriculture's environmental effects and excludes, for example, impacts on biodiversity.

value of outputs and production inputs, various GHG emissions and total global warming potential of crop and milk production, ammonia emissions, and feed inputs.

79. A clustering approach is adopted which allows data to be grouped on the basis of similarity across production technologies on the basis of a set of agricultural production data from the CAPRI database.

80. The following procedure is used in the clustering:

- Obtain relevant data from the CAPRI database and generate a new data file with identifiers based on region;
- Estimate a range of parameters of variable means, variances and co-variances for a range of cluster numbers from 1-15 clusters;
- Consider the “best” clustering model on the basis of statistical criteria, checking for logical consistency in estimated clusters and that clusters include at least several observations (the clustering process is described in **Annex B**);
- Generate a clustering classification on the basis of the chosen clustering model along with parameters associated with those clusters.

81. The clustering procedure yielded an optimal assignment of regions to 8 clusters. Table 2.1 presents the means of each variable used in the clustering procedure for these clusters. As shown, there is substantial variance between the groups with both high-intensity crop or dairy production regions and low-intensity regions associated with lower gross margins (typically but not ubiquitously).

Table 2.1. Means for clustering variables used in this analysis

	Unit	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
Soft wheat	kg/ha	6487	2827	4369	4699	2820	2675	5071	3481
Barley	kg/ha	5428	3279	3825	3993	2876	2751	4519	2963
Milk production	kg/cow	6908	8353	6259	4169	4850	9866	4801	4450
Gross-margin for crops	EUR/ha	2110	1398	1269	605	-181	2041	1639	1312
Gross-margin for dairy	EUR/cow	8594	6803	7799	5859	6250	10179	6402	5240

Note: A negative gross margin is interpreted as the revenue from production being smaller than the variable cost of production.

Source: Own estimations.

82. The bio-economic model calibration approach draws on the idea of Positive Mathematical Programming (PMP), that is, it is assumed that the statistically observed data are the outcome of economically rational choices of the farmers. Assuming further that the structure and the parameterisation of the model reflects the optimisation problem of the farmers, we need to adjust at least one parameter for each endogenous variable for calibration. The calibration must choose parameter values such that first-order conditions (FOCs) hold at the calibration point. In order to avoid that a degenerate primal solution results from the calibration step, a non-linear function must be used to allow for interior solution away from the outer hull of the convex set defined by the linear constraints and bounds on variables such as non-negativity conditions.

83. In the current model structure, crop and milk yield responses are continuous and non-linear, and thus react mostly smoothly to changes in input and output prices. This is

not the case for acreage decisions, which therefore tend to produce corner solutions (i.e. whole acreage allocated to the most profitable crop). In order to avoid corner solutions, an amount of variable costs for each arable crop was introduced, which changes with the land use share of the crop. To keep the approach transparent, it is assumed that some additional costs (or utility losses) increase linearly from zero to 50% of the per hectare revenues over the potential range of a crop share from zero to unity. The optimisation will yield the shadow prices of these calibration constraints, which are subsequently used to define the variable cost.

84. For policy simulations, the total land area in each cluster is scaled to 100 ha. Thus, clusters are put on equal footing regarding land endowment, which facilitates comparison of the impact of differential crop and milk productivity and profitability on farms' responses to policy instruments.

Policy scenarios and results

Policy scenarios

85. To analyse the potential productivity and environmental sustainability impacts of agricultural support policy instruments, we simulate six separate instruments, drawn from the following PSE categories:

- A. Support based on commodity output (A1. Market Price Support):
 - Instrument 1: simultaneous 10% increase in output price for crops (wheat, barley and rapeseed)
 - Instrument 2: 10% increase in milk price (separate to Instrument 1)
- B. Payments based on input use (B1. Variable input use):
 - Instrument 3: 10% input subsidy for chemical nitrogen fertiliser
- C. Payments based on current A/An/R/I, production required (C2. Based on current area or animal numbers):
 - Instrument 4: EUR 100/ha payment simultaneously for barley, wheat, and rape
 - Instrument 5: EUR 380/head payment for dairy cow (separate to instrument 4)
- E. Payments based on non-current A/An/R/I, production not required (E2. Fixed rates based on Area):
 - Instrument 6: EUR 100/ha for all land uses (barley, wheat, rape, silage, pasture and green set-aside)

86. To ensure an equal footing for policy analysis, payment levels for each instrument were determined so that their relative impacts on *ex ante* profits per ha for crops or per head of animal are the same. Uniform payment levels are applied to all clusters.

Results

87. Table 2.2 presents the baseline situation for the three clusters (1, 6 and 7) selected for results reporting to illustrate different conditions regarding crop and milk yields, production costs, environmental outcomes and profitability.²⁰

Table 2.2. Baseline situations of the clusters

	Cluster 1	Cluster 6	Cluster 7
Herd size, dairy cows	24	26	23
Land allocation, ha: CO:SiP:SeGSe ¹	55:45:0	48:52:0	38:62:0
Wheat yield, kg/ha	6469	2623	5032
Nitrogen fertiliser application, kg/ha ²	157	65	130
Milk, kg/dairy cow /year	6926	7907	4844
Total GHG emissions, kg CO ₂ -eq./year	427 287	414 045	397 461
Nitrogen runoff, kg/year	1270	863	1055
Phosphorus runoff, kg/year	53	44	37
Sustainable productivity, index value	1.00	1.00	1.00
Value of environmental damage relative to production value, €/€ ²¹	0.174	0.186	0.242
Profit, EUR/year	131 187	78 573	74 227
CAP support payments, % of profit	51	61	80

Notes: 1. Cereals and oilseeds (CO), grass silage and pasture (SiP), and set-aside and green set-aside (SeGSe).

2. Nitrogen fertiliser application combines chemical fertiliser and manure nitrogen inputs.

88. Cluster 1 represents relatively high milk and crop yields, and devotes 45% of the land area for grass silage and pasture for dairy production purposes. Nitrogen fertiliser intensity is high and reflects high crop yields, which are the highest among analysed clusters. Total GHG emissions are the highest among the analysed clusters and reflect both dairy cow number (herd size 24) and high intensity of crop cultivation. Since a relatively high share of the land area (55%) is allocated to intensive cereals and oilseeds production also nitrogen and phosphorus runoff are the highest among analysed clusters.

89. Cluster 6 represents relatively low crop yields and relatively high milk yields. Due to lower crop productivity and thus also silage and pasture yields dairy cow feeding in Cluster 6 is based relatively more on concentrates than in Cluster 1. Higher concentrate feeding supports the highest milk yields among the analysed clusters. Despite larger dairy herd size, the total GHG emissions are smaller than in Cluster 1. This is due to significantly lower nitrogen fertiliser intensity for cereals and oilseeds. Also nitrogen and phosphorus runoff are lower than in Cluster 1 because of lower fertiliser intensity and larger land use share of grass silage and pasture, which have smaller propensity to runoff than cereals and oilseeds.

²⁰ To facilitate results reporting and discussion, 3 out of 8 clusters were selected based on large variation of crop and milk productivity and profitability.

²¹ This indicator measures the emission intensity of production and is reported in order to provide additional information regarding environmental sustainability impacts of policy instruments. In calculating this indicator, social valuation estimates are used to monetise environmental effects (nitrogen and phosphorus runoff and GHG emissions). In this indicator, total environmental damage (sum of the social damage from nitrogen and phosphorus runoff and GHG emissions) is divided by the total value of commodity production. Social valuation estimates used in calculation of this indicator are reported in Annex A.

90. Cluster 7 represents the lowest milk yields among analysed clusters. Dairy cow feeding in this cluster is mainly based on grass silage and pasture and the share of concentrates is the lowest among analysed clusters. Crop yields and fertiliser intensity are lower than in Cluster 1, but clearly higher than those of Cluster 6. Due to having the smallest dairy herd size, total GHG emissions are the lowest among analysed clusters, while nitrogen and phosphorus runoff are higher than in Cluster 6 because of higher fertiliser intensity for cereals and oilseeds.

91. Baseline profits include Common Agricultural Policy (CAP) support payments for crops. Cluster 1 represents the highest profit cluster in which the share of CAP support payments from profit is 51%. For less profitable Clusters 6 and 7, the share of support payments from profits is 61% and 81%, respectively.

92. Table 2.3 presents the environmental and sustainable productivity impacts for the six policy instruments analysed.²² These are driven by the impact of policy instruments on input use intensity, number of dairy cows and land allocation between cereals/oilseeds and grass silage/pasture.

Table 2.3. Impacts of policy instruments (% change relative to baseline)

	Cluster 1	Cluster 6	Cluster 7
1: Market price support for crops			
Land allocation to grass silage and pasture	-27.8	-11.6	-16.4
Total GHG emissions, kg CO ₂ -eq./year	+0.4	-1.1	+0.8
Nitrogen runoff, kg/year	+15.4	+3.7	+10.0
Phosphorus runoff, kg/year	+22.0	+12.3	+25.1
Profit, EUR/year	+1.0	+2.6	+4.6
Sustainable productivity, index value	-6.0	-3.0	-3.0
Value of environmental damage relative to production value, €/€	+13.3	+8.7	+6.4
2: Market price support for milk			
Land allocation to grass silage and pasture	-1.1	-0.3	-4.1
Total GHG emissions, kg CO ₂ -eq./year	+1.8	+1.2	+0.5
Nitrogen runoff, kg/year	+0.1	0.0	+0.6
Phosphorus runoff, kg/year	+0.9	+0.3	+6.3
Profit, EUR/year	+7.4	+13.7	+10.3
Sustainable productivity, index value	+1.0	+2.0	+9.0
Value of environmental damage relative to production value, €/€	-3.7	-4.3	-12.1
3: Payments based on input use			
Land allocation to grass silage and pasture	-6.9	0.0	-2.1
Total GHG emissions, kg CO ₂ -eq./year	+4.2	+2.2	+0.2
Nitrogen runoff, kg/year	+6.4	+3.2	+1.5
Phosphorus runoff, kg/year	+5.5	0.0	+3.3
Profit, EUR/year	+2.5	+3.1	+2.2
Sustainable productivity, index value	-1.0	+1.0	+1.0
Value of environmental damage relative to production value, €/€	-1.0	-1.1	+1.2
4: Payments based on current area of crops			
Land allocation to grass silage and pasture	-25.0	-27.9	-21.1
Total GHG emissions, kg CO ₂ -eq./year	+0.3	-2.6	+1.0

²² Impact of policy instruments on traditional total factor productivity (without environmental impacts) is provided in Table A C.1. TFP under different policy instruments relative to the Baseline).

	Cluster 1	Cluster 6	Cluster 7
Nitrogen runoff, kg/year	+13.2	+8.9	+12.5
Phosphorus runoff, kg/year	+19.7	+29.5	+32.5
Profit, EUR/year	+4.6	+6.9	+6.0
Sustainable productivity, index value	-6.0	-9.0	-5.0
Value of environmental damage relative to production value, €/€	+12.0	+23.9	+8.7
5: Payments based on current animal numbers			
Land allocation to grass silage and pasture	+8.6	+16.1	+8.9
Total GHG emissions, kg CO ₂ -eq./year	+4.1	+1.0	-0.3
Nitrogen runoff, kg/year	-0.5	-1.3	-5.1
Phosphorus runoff, kg/year	-6.8	-17.0	-13.6
Profit, EUR/year	+9.1	+15.2	+14.4
Sustainable productivity, index value	-6.0	-2.0	+2.0
Value of environmental damage relative to production value, €/€	+7.8	+0.3	-3.4
6: Payments based on non-current area			
Land allocation to grass silage and pasture	0.0	0.0	0.0
Total GHG emissions, kg CO ₂ -eq./year	0.0	0.0	0.0
Nitrogen runoff, kg/year	0.0	0.0	0.0
Phosphorus runoff, kg/year	0.0	0.0	0.0
Profit, EUR/year	+7.7	+12.9	+13.6
Sustainable productivity, index value	0.0	0.0	0.0
Value of environmental damage relative to production value, €/€	0.0	0.0	0.0

93. **Market price support for crops** increases the profitability of crop production relative to dairy production. The number of dairy cows decreases, and therefore required land area for grass silage and pasture decreases in all clusters. Although the number of dairy cows decreases, total GHG emissions increase in Clusters 1 and 7. This is due to increased fertiliser intensity for crops and increased allocation of land to cereals and oilseeds, emissions from which more than offset GHG emissions reductions from lower dairy herds. For water quality, both nitrogen and phosphorus runoff increase due to higher intensity of fertiliser use and increased allocation of land to cereals and oilseeds, which each have a higher propensity for nutrient runoff than grass silage and pasture.

94. As described above, the sustainable productivity index is the ratio between produced output quantity and input quantity in which GHG emissions and nutrient runoff are incorporated on the input side as they represent a use of the natural resources and other environmental services. Under market price support for crops, the sustainable productivity index value decreases relative to the Baseline (baseline index value equals 1.00) in all clusters. This is because output quantity decreases and input quantity increases. The increase in input quantity is mainly due to an increase in environmental inputs (that is, environmental damage). Similarly total value of environmental damage relative to total value of production increases in all Clusters.

95. **Market price support for milk** increases dairy cow numbers, but decreases land allocation to grass silage and pasture due to decreased use of roughage and a shift towards feeding of concentrates. Due to increased dairy herd size total GHG emissions slightly increase in all clusters. As a consequence of land allocation change from grass silage and pasture to cereals and oilseeds, nitrogen and phosphorus runoff also increase slightly,

although fertiliser intensity is not affected. The impact on nutrient runoff is largest for Cluster 7, in which largest land use change takes place.

96. The sustainable productivity index increases relative to the Baseline in all clusters. Both output quantity and input quantity increase, but output increases relatively more than input quantity. Within input quantity, both production and environmental inputs increase. This result shows the limitations of the sustainable productivity index indicator: under market price support for milk, its value increases relative to the baseline, even though nutrient runoff and GHG emissions all increase for Clusters 1, 6 and 7 (with the exception of N runoff for Cluster 6, which shows no change). This occurs because this index implements a *weak sustainability* approach; i.e. it allows for full substitutability between environmental inputs and traditional agricultural inputs. Output increase and increase in total value of production is also reflected in the value of environmental damage relative to the value of production which decreases in all Clusters relative to the Baseline.

97. **Payments based on input use** (chemical nitrogen fertiliser) favours crop production over dairy production and land allocation shifts towards cereals and oilseeds and away from silage and pasture in Clusters 1 and 7. Fertiliser costs decrease and use increases. As a result, total GHG emissions increase in all clusters. Due to land allocation change towards cereals and oilseeds in Clusters 1 and 7, both nitrogen and phosphorus runoff increase. As there is no land allocation change in Cluster 6, phosphorus runoff does not change, but nitrogen runoff increases due to increased fertiliser use.

98. The sustainable productivity index decreases in Cluster 1 relative to the Baseline, while it increases in Clusters 6 and 7. In Cluster 1 input quantity increases slightly more than output quantity and both production inputs and environmental inputs increase relative to the Baseline. In Clusters 6 and 7 output quantity increase more than input quantity. Within input quantity environmental inputs increase more than production inputs. Total value of environmental damage relative to total value of production slightly decreases in Clusters 1 and 6, while it increases in Cluster 7.

99. **Payments based on current area of crops** (cereals and oilseeds) have a strong impact on land allocation and dairy cow numbers. Land allocation shifts to cereals and oilseeds and dairy cow numbers decrease. Although dairy cow numbers decrease total GHG emissions increase slightly in Clusters 1 and 7 as GHG emissions from cultivation and fertiliser use increase (fertiliser intensity is not affected), which offset decrease in dairy cow numbers. In Cluster 6 total GHG emissions decrease as total fertiliser use increase is relatively small. Both nitrogen and phosphorus runoff increase strongly in all clusters, which is mainly due to land allocation change towards cereals and oilseeds.

100. The sustainable productivity index decreases in all clusters as output quantity decreases and input quantity increases. Input quantity increase comes from strong increase of environmental inputs. This is also reflected in significant increase of the total value of environmental damage relative to the value of production.

101. **Payments based on current animal numbers** significantly (9-29%) increase number of dairy cows and land area allocated to grass silage and pasture (9-16%). Total GHG emissions increase in Clusters 1 and 6 as increased methane emissions from enteric fermentation due to increased dairy herd size more than offset decreased GHG emissions from fertiliser and cultivation practices. In Cluster 7 reduced GHG emissions from fertiliser and cultivation practices more than offset increased methane emissions due to small increase in dairy herd size (from 23 to 25). Both nitrogen and phosphorus runoff decrease

in all clusters as more land is allocated grass silage and pasture that have less propensity to nutrient runoff due to their permanent type of land cover.

102. Sustainable productivity index decreases in Clusters 1 and 6 mainly due to decrease in output while input quantities (production and environmental inputs) are close to those under the Baseline. In Cluster 7, index value increases since output quantity is same as in the Baseline, but input quantity (both production and environmental inputs) decreases.

103. **Payments based on non-current area** have no impact on farmers' production decisions at the intensive or extensive margin (assuming farmers are risk-neutral). Thus, they have no impact on input use and land allocation and consequently on the environment. Also sustainable productivity index value and the total value of environmental damage relative to the value of production remain same as in the Baseline.

104. Market price support for crops or for milk appear to increase GHG emissions and nutrient runoff in almost all clusters (with the exception of decreasing total GHG emissions in Cluster 6 under market price support for crops and having zero impact on phosphorus runoff in Cluster 6 under market price support for milk). Payments based on input use (nitrogen fertiliser subsidy) also seem to have negative environmental effects in terms of GHG emissions and nutrient runoff in all analysed clusters (with exception of zero impact on phosphorus runoff in Cluster 6). Payments based on current area of crops appear to increase nutrient runoff in all clusters, while their impact on total GHG emissions is more equivocal and dependent on how dairy cow numbers adjust to changes in relative profitability of crop and dairy production. Similarly, payments based on current animal numbers seem to decrease nutrient runoff in all clusters by increasing land allocation towards grass silage and pasture that are less prone to nutrient runoff than cereals and oilseeds. Their impact on total GHG emissions is more equivocal as they increase emissions in Clusters 1 and 6 and slightly decrease those in Cluster 7. The impact on total GHG emissions depends on whether increased methane emissions from enteric fermentation due to increased dairy herd size more than offset decreased GHG emissions from fertiliser and cultivation practices. In Clusters 1 and 6 this is the case, while in Cluster 7 reduced GHG emissions from fertiliser and cultivation practices more than offset increased methane emissions due to small increase in dairy herd size.

105. Overall, these results show that for some of the agricultural support measures, the environmental impacts are relatively consistent across clusters. This is the case for market price support, payments based on input use, and payments based on non-current area of crops. For others, including payments based on current area of crops and on animal numbers, they differ somewhat due to differential conditions of these clusters regarding milk and crop productivity, and thus their response (e.g. adjustment of dairy cow numbers) to these policy instruments may differ. Moreover, although intensive margin decisions, such as fertiliser application intensity and livestock feeding, affect environmental effects of support measures, the environmental effects seem to be driven mainly by extensive margin decisions: (i) land allocation between cereals and oilseeds and grasslands (grass silage and pasture) and (ii) dairy cow numbers. Thus, extensive margin impacts appear to dominate intensive margin impacts in this study. Reasons for this are as follows. In the case of nutrient runoff, the difference in nutrient runoff propensity between different land uses (cereals and oilseeds versus grasslands) is relatively large and dominates the intensive margin impact of increased or decreased fertiliser application intensity. In the case of GHG emissions, livestock feeding (intensive margin decision), while affecting the total GHG emissions, is dominated by the number of animals (extensive margin impact).

106. As regards sustainable productivity, the results suggest that only support measure that increases sustainable productivity in all clusters relative to the Baseline is market price support for milk. Payments based on current area of crops and market price support for crops decrease index value in all clusters, while payments based on non-current area are consistently neutral across clusters. For rest of the policy instruments (payments based on input use and payments based on current animal numbers) sustainable productivity impacts are somewhat differ across clusters. For payment based on input use, Cluster 1 differs from Clusters 6 and 7 because of large increase in environmental inputs (environmental damage). For payment based on current animal numbers, Cluster 7 differs from other clusters due to smaller environmental damage.

Conclusions

107. This chapter explored the linkages between agricultural support policies and sustainable productivity, using a relatively new sustainable productivity index approach. It focuses on the main categories of agricultural support policies based on the OECD Producer Support Estimate (PSE) classification and examines the support measures most relevant to sustainable productivity performance. The bio-economic farm model is applied based on data representing various EU countries' situations. Thus, the results are, as a consequence, most applicable to countries in the European Union, although they remain relevant for other countries with production systems similar to those covered in the three clusters reported in this analysis. The analysis focuses on GHG emissions and water quality (through nitrogen and phosphorus runoff) and sustainable productivity.

108. Based on the model specification, the data used and the selected environmental and sustainable productivity indicators, the results from this analysis seem to suggest that market price support for crops or for milk and payments based on input use have the most consistent negative impacts on environment among the various PSE measures. The environmental impacts of payments based on current area of crops or current number of animals are more equivocal between different environmental impacts and different production conditions (clusters). If support is based on current animal numbers then nutrient runoff likely decreases and GHG emissions increase, while likely environmental impacts are opposite when support is based on current area of crops (GHG emissions decrease and nutrient runoff increases). The environmental impacts of non-current crop area payments (decoupled payments) appear to be zero (or neutral) and thus they seem to be among the least environmentally harmful support policies.

109. Overall, these results show that for some of the agricultural support measures, the environmental impacts are relatively consistent across clusters. This is the case for market price support, payments based on input use, and payments based on non-current area of crops. For payments based on current area of crops and on animal numbers, results may differ somewhat due to differential agricultural conditions of the clusters regarding milk and crop productivity. Thus farmers' adjustment with respect to these policy instruments may differ, including decisions on land allocation and dairy cow numbers.

110. Moreover, extensive margin impacts appear to dominate intensive margin impacts in this model application. Although agricultural support policies, especially market price support and payments based on input use, also affect intensive margin decisions (such as fertiliser application intensity and livestock feeding), the environmental effects seem to be driven mainly by extensive margin decisions (shifting between land uses) in this application. Thus, in addition to intensive margin impact it is important to consider how agricultural policies operate at the extensive and entry-exit margins.

111. Impacts of support policies on sustainable productivity suggest that only one support measure (market price support for milk) consistently increases (weak) sustainable productivity across analysed clusters relative to the Baseline. Crop-related support (payments based on current area of crops and market price support for crops) consistently decrease the index value in all clusters, while rest of the payments have either neutral impacts (payments based on non-current area) or impacts differ across clusters (payments based on input use and payments based on current animal numbers). As in the case of individual environmental impacts, sustainable productivity impacts are also driven by extensive margin impacts of policies, which explains why support policies for crop production perform poorly; they decrease output quantities and increase environmental inputs (mainly nutrient runoff). The strong impact of market price support for milk is explained by strong impact on output quantity, with moderate impact on input quantity (including both production and environmental inputs).

112. It is worth emphasising that there are limitations related to data, adopted clustering approach and various modelling assumptions, which affect the results. Moreover, the insights of this analysis are limited to the farming systems and regions that were considered in this model application; that is, they primarily apply to mixed farming systems within Europe or similar systems elsewhere. As such, the data and parameters used in this model represent the agronomic and economic conditions in these systems. The analysis of other farming systems, such as more specialised farms in other OECD countries with different economic and agronomic conditions, could generate different analytical findings.

3. Using fuzzy set qualitative comparative analysis to examine pathways towards sustainable, productive agriculture

Introduction

113. As an empirical method, QCA allows identification of complex interactions that may exhibit three characteristics: equifinality, conjunctural causation, and causal asymmetry (Wagemann and Schneider, 2010^[28]). Equifinality means that various combinations of exogenous factors (such as market price support, lack of environmental regulations, high livestock density) may be sufficient to produce the same outcome of interest (high nitrogen surplus) — i.e. that there may be multiple pathways to the same outcome. Conjunctural causation refers to a situation where an exogenous factor (market price support) is sufficient for producing a given outcome (high nitrogen surplus) only when combined with other factors (high livestock density). Causal asymmetry implies that sufficient conditions (e.g. a combination of market price support and high livestock density) for the presence of an outcome (high nitrogen surplus) are not necessarily a mirror image of sufficient conditions for its absence (that is, a low level of market price support combined with a low level of livestock density does not necessarily lead to a low level of nitrogen surplus).

114. The context of agricultural policies likely exhibits these three characteristics and therefore QCA provides a tool for understanding complex relationships between agricultural policies, productivity and environmental sustainability performance. To this end, data from OECD agri-environmental and PSE databases is employed in order to reveal potential pathways for environmental sustainability performance outcomes and to investigate the role of agricultural policies relative to other factors in shaping this performance.

115. The chapter is organised as follows. Conceptual framework is developed in the second section. The third section provides a brief description of the method and data used for analysis. Results and discussion are provided in section four, while section five concludes.

Conceptual Framework

116. This analysis employs a categorisation of agricultural support policies based on the OECD Producer Support Estimate (PSE) classification of agricultural support instruments. Economic theory and findings from literature (e.g. OECD (2010^[29]), Henderson and Lankoski (2019^[24])) suggest that the environmental impacts of agricultural policies can be explored by analysing policy instrument's impacts on three margins: (i) intensive, (ii) extensive and (iii) entry-exit.

117. **Market price support and payments based on output (category A)** provide incentives for intensification of input use (intensive margin impact), allocation of land for supported crops (extensive margin impact), and increased entry of land to agriculture sector (entry-exit margin impact).

118. **Payments based on input use (category B)**, for example fuel, fertiliser and pesticides, provide incentives for intensification of input use, may affect land allocation by

favouring crops requiring higher level of subsidised inputs and affect entry-exit margin by increasing profitability of agriculture relative to other land uses.

119. **Payments based on current production parameters (category C)** are assumed not to have an intensive margin impact (they do not affect input use intensity),²³ but affect extensive margin if non-uniform payment rates are applied; that is, payment rates differ between different crops. Due to profitability increase, they also provide incentives for agricultural area expansion relative to other land uses (entry-exit margin).

120. **Decoupled payments (categories D and E)** allow farmers to follow market signals in their production decisions, including the choice not to produce at all (category E). Because the payments are based on parameters that are fixed (usually historical), there is no incentive to increase production at either the intensive or extensive margin.²⁴ If historical acreage is fixed for payments then there is no incentive to bring additional land into sector (no entry). On the other hand, these payments increase profitability of agriculture relative to other land uses, and thus hinder exit from the sector. Overall, these payments are expected to lead to fewer environmental pressures (neutral environmental impacts) relative to other categories of support (A, B, and C). Further, it is expected that input constraints (indicated by PSE labels) linked to different support categories (B, C, D, and E) have the potential to contribute to improving environmental performance of agriculture compared with a situation where the same level and structure of payments are made without any conditions attached.

121. Henderson and Lankoski (2019_[24]) conclude — on the basis of the models employed in their study, the selected environmental indicators, and data used — that market price support and payments based on input use (PSE categories A and B) are the most environmentally harmful among the various PSE measures. For payments based on current area or animal numbers, environmental impacts are more equivocal in different country and farm situations and depend on specific production and market conditions. From analysed policy instruments, payments based on non-current area are among the least environmentally harmful support policies.

122. Table 3.1 summarises the potential impacts of different agricultural support categories on three margins.

²³ As noted in the literature review on impacts of agricultural policies, some studies of “coupled support” find that coupled payments are associated with increased fertiliser and chemical use, which suggests an intensive margin impact. However, such studies generally do not enable identification of the exact nature of coupled support. This assumption is therefore justified with reference to economic theory, which suggests that, because Category C payments are based on current animal numbers or current area rather than being linked to output, they do not encourage producers to increase yields (or animal numbers per unit of area), and therefore do not have a significant impact on incentives at the intensive margin.

²⁴ In many countries, eligibility for decoupled payments is determined by a fixed, historical base, so that cropland expansion does not take place as a result of the policy. Expectations regarding future updates of historical base area may create incentives for cropland expansion in the longer run in countries with available land.

Table 3.1. Impact of agricultural support categories on three margins

PSE category	Intensive margin	Extensive margin	Entry-exit margin
A. Support based on commodity output	X	X	X
B. Payments based on input use	X	X	X
C. Payments based on current A/AN/R/I, production required		X	X
D. Payments based on non-current A/AN/R/I, production required			(X)
E. Payments based on non-current A/AN/R/I, production not required			(X)

Note: (X) If historical acreage is fixed for D and E category payments then there is no incentives to bring additional land into sector (no entry). Since these payments increase profitability of agriculture relative to other land uses they hinder exit from the sector and thus have an impact on entry-exit margin.

123. The findings in Henderson and Lankoski's (2019^[24]) modelling study suggest that in OECD countries, coupled support policies (market price support and payments based on input use or outputs) are the most environmentally harmful. Their results are less clear for payments based on current crop area. Depending on the circumstances, such payments could increase the competitiveness of crops relative to livestock or of some crops relative to others; the environmental effect then depends on the emission intensity of each commodity. Similarly, coupled support policies favouring one commodity over others could have positive or negative environmental effects depending on the relative emission intensities of the commodities. Fully decoupled payments are among the least environmentally harmful support policies. Moreover, subjecting agricultural support payments to environmental constraints, such as fertiliser and pesticide application limits, can improve environmental performance outcomes compared to support payments without restrictions. These findings are consistent with the empirical literature reviewed in (OECD, 2019^[3]) and (DeBoe, 2020^[4]).

124. The main findings from the literature investigating the impact of agricultural and agri-environmental policies on productivity are as follows (DeBoe, 2020^[4]). Most studies find a negative relationship between agricultural support levels (i.e. support payments per farm, per hectare, etc.) and productivity (as measured either through technical efficiency or Total Factor Productivity, TFP). For crop farms, coupled payments (e.g. payments linked to current output, receipts, crop area, livestock numbers) and total level of support payments most often have a negative impact on farm level technical efficiency or TFP, while decoupled payments tend to have a neutral (or statistically non-significant) impact. The result for coupled payments also holds for dairy farms and non-dairy livestock farms. Hence, coupled payments from PSE categories A to C are likely to have negative impact on productivity while decoupled payments from categories D and E are likely to have neutral impact on productivity.

125. On the basis of economic theory and the above discussion the following hypothesis will be analysed in what follows:

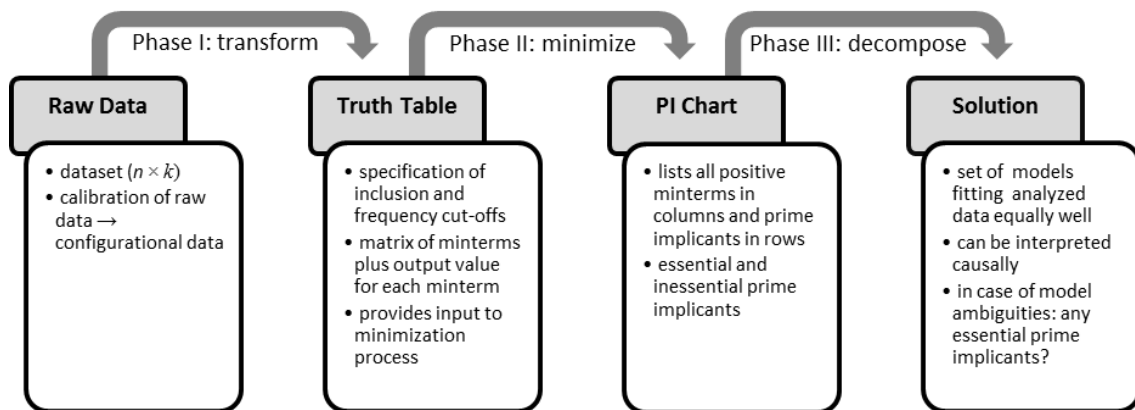
- **Hypothesis:** Countries with low level of agricultural support in categories A, B or C (support based on commodity output, payments on input use or payments based on current area or animal numbers, respectively) are more likely to have high sustainable productivity performance (combined productivity and environmental sustainability performance) than those countries with high level of support in categories A, B and C or those which do not attach environmental requirements with category D and E payments.

Methodology and Data

Methodology

126. The aim of QCA is to identify conditions, or combinations of conditions, that are *necessary* or *sufficient* for an outcome. Condition X is necessary for outcome Y if Y never occurs without X. Condition X is sufficient for outcome Y if whenever X occurs Y also occurs. In set-theoretic terms, a necessary relation exists when the outcome Y is a subset of the condition X, while a sufficient relation exists when X is a subset of Y. The procedural protocol of QCA, as visualised in Figure 3.1 can be divided into three phases (Thiem, 2017, p. 243_[30]): the transformation of raw data into a “truth table” (Phase I), the minimisation of the function described by the truth table to a prime implicant (PI) chart (Phase II), and the decomposition of this chart for deriving the solution (Phase III).

Figure 3.1. Procedural protocol of QCA



Source: adapted from phases in Thiem (2017, p. 243_[30]).

127. Similar to the requirements of other formal methods of causal data analysis, the main input to QCA is a data set of dimension $n \times k$, with n being the number of cases (rows) and k the number of conditions and outcomes (columns). These data are referred to as “raw data”.

128. As noted in Figure 3.1, QCA requires raw data to be transformed into configurational data via the process of calibration. Calibration translates raw variables into factors, whose levels provide the basis for meaningfully defined sets of interest (Thiem, 2014_[31]). In this application, set membership scores are determined through a process called transformational assignment, in which a mathematical function is used whose parameters incorporate certain internal or external criteria. The specific variant of QCA used in this application is that of fuzzy-set QCA (fsQCA), which uses theory-based transformation to construct the assignment function. Theory-based transformation requires substantive knowledge of the base values of the conditions and outcomes in relation to existing theoretical and empirical knowledge. The first step in calibration is to define the following calibration thresholds:

- The **exclusion** threshold: the value at which a country should be fully out of a set (set membership score of 0)

- The **inclusion** threshold: the value at which a country should be fully in a set (set membership score of 1)
- The **crossover** threshold: the point of maximum ambiguity where a country is as much in a set as out of it (set membership score of 0.5).

129. Cases on different sides of the crossover point are qualitatively different, while cases on the same side of the crossover point differ in degree through their different membership scores.

130. An important feature of fuzzy-set analysis is that degrees of set membership are considered. For example, while country A might be clearly in a set (set membership score of 1), country B might belong to the set less clearly than country A, but more clearly than country C. In this case, both country B and C should be assigned some value between 0.5 and 1, but the question remains of how to assign these values. This aspect of calibration is the choice of a membership function. Our analysis uses a piecewise linear transformation function that applies the respective thresholds to each variable to map raw values into the unit interval $[0, 1]$ to create a “fuzzy number”, indicating the degree to which each country belongs to the set of countries that meet the condition of interest.

131. Once all conditions and outcomes have been calibrated, the truth table analysis can be started. Truth table analysis helps to identify patterns of sufficiency; that is, combinations of conditions (or “causal recipes”) that are sufficient to produce a particular outcome. The truth table analysis is the core element of formal QCA data analysis and consists of converting fuzzy sets into a truth table and minimising the sufficient configurations in the truth table to more parsimonious configurations (Legewie, 2013^[32]).

132. Truth table analysis yields three different solutions: (i) complex, (ii) parsimonious, and (iii) intermediate solution. The complex solution shows *all* the causal pathways, which produce a particular outcome. It does not allow use of simplifying assumptions (theory and substance driven assumptions of how a certain condition may be related to the outcome), and thus it usually results in a solution that is relatively complex, especially when there are many conditions (Legewie, 2013^[32]). The parsimonious solution reduces the configurations to the *smallest number of conditions possible*, and the conditions included in that solution are called “prime implicants”—these are the conditions that cannot be left out of the solution to the truth table. The intermediate solution arises from the fact that real-world case studies generally do not provide data on all the logically possible combinations of the conditions, so there may be no data on whether a particular “recipe” of conditions produces a particular outcome or not. The intermediate solution uses counterfactual analysis guided by expert opinion to make simplifying assumptions in order to reduce the complexity of the solutions that arises due to this absence of data. It can be used when there is clear theoretical and empirical knowledge of how certain conditions contribute to the outcome.

133. For each of the solutions (complex, parsimonious, or intermediate) the output of truth table analysis provides the configurations or relational pathways (after the Boolean minimisation procedure) that are sufficient for the outcome. A number of metrics allow for the assessment of the different configurations: *raw coverage*, *unique coverage*, and *inclusion (also called consistency) scores*. Coverage and inclusion scores are also provided for the overall solution (i.e. the set of configurations). Raw coverage shows what proportion of the outcome (e.g. countries exhibiting a certain performance) is covered by a configuration. Unique coverage shows what proportion of the outcome is uniquely covered by that configuration. The inclusion score shows how consistently cases represented by a given configuration display the outcome; that is, whether there are cases in a configuration

that do not display the outcome and thus deviate from the patterns identified by QCA (Legewie, 2013_[32]). In statistical terms inclusion (or consistency) resembles significance and coverage resembles R^2 (Thiem, 2010_[33]). Finally, the product of the inclusion and coverage gives the general strength of a causal model.

Data

134. Raw data for analysis is presented in **Annex D**. For calibration of raw data, it has to be decided at which value a country should be fully out of a set (set membership score of 0), fully in a set (set membership score of 1), and where it should be as much in the set as out of it (set membership score of 0.5). These three set membership scores are called *calibration anchors*, and the specific values of the variables that should be mapped onto these anchors are called calibration thresholds. The threshold for full membership is the *inclusion threshold*, that for full non-membership the *exclusion threshold* and that at the point of maximum ambiguity the *crossover threshold*.

135. Table 3.2 lists all outcomes and conditions. The following outcomes (endogenous variables) are included in the analysis. For productivity outcome a total factor productivity (TFP) growth estimate is employed. For environmental effects, three outcomes are included. Greenhouse gas (GHG) emissions per ha of agricultural land serves as a proxy of climate change impact of the sector. Nitrogen surplus (NS) kg/ha is a proxy indicator for potential water quality impacts of nitrogen runoff and leaching. Phosphorus surplus (PS) kg/ha serves as a proxy indicator for potential water quality impacts of phosphorus runoff.

136. In addition, three sustainable productivity outcomes have been developed, which combine productivity growth and three environmental sustainability outcomes.

- *Sustainable Productivity — Strong (SPS)*: a strong sustainability rule is adopted, which means that a low performance in one of the environmental sustainability dimension *cannot* be substituted for high performance in other environmental sustainability dimensions. Similarly, combined productivity and environmental sustainability (that is, SPS) does not allow substitution between the two elements of sustainable productivity (i.e. no substitution allowed between sustainability and productivity outcomes). Thus, the minimum of the three calibrated environmental sustainability values (GHG, NS, and PS) is selected and then the minimum of this value and the calibrated value of productivity (TFP) is selected to get *SPS*.
- *Sustainable productivity — semi-strong (SPSS)*: first the minimum of calibrated values for environmental dimensions GHG, NS, PS is selected and then an average of that and calibrated value for productivity (TFP) is selected to get *SPSS*. Here environmental performance and productivity performance freely substitute each other, but there is no substitution possibility among environmental dimensions.
- *Sustainable Productivity—Weak (SPW)*: a weak sustainability rule is adopted which allows substitution between different environmental outcomes and between productivity and environmental sustainability outcomes. Thus, substitution between environmental dimensions is allowed by taking an average of calibrated values of GHG, NS, and PS and then an average of that and calibrated value for productivity (TFP) to get *SPW*.

137. Conditions (exogenous variables) are grouped in two sets. The first set of exogenous variables relate to structure and intensity of agricultural production described by chemical fertiliser or manure nitrogen or phosphorus application intensity per ha of

agricultural land. The second set of exogenous variables relate to agricultural support policy.

138. It is useful to note that the data regarding agricultural support policies, production structure and intensity, and environmental outcomes are contemporaneous and from a single year (2015). This means that, given the likely lagged response of some production and structure- and intensity-related conditions to policy changes, the support policy related conditions should not be interpreted as fully representing the influence of policies. Rather, they could represent the marginal impact of a single year of payments under the different categories, taking past policies and their impact on production structures as given.

139. Because of the assumption (see Table 3.1) that category C payments do not affect the intensive margin, a less strong relationship is expected between category C payments and contemporaneous environmental outcomes than is the case with payments from categories A and B.

Table 3.2. Factors, data sources and measurement scale

	Conditions and outcomes	Data source	Measurement scale
Outcomes (Endogenous factors)	Country with high agricultural productivity, total factor productivity (TFP)	Average annual growth rate of total factor productivity (TFP) over the period 2005-2014; USDA, 2017	%
	Country with high level of nitrogen surplus (NS)	2015; OECD AEI database	Kg/ha
	Country with high level of phosphorus surplus (PS)	2015; OECD AEI database	Kg/ha
	Country with high level of greenhouse gas emissions (GHG)	2015; OECD Agri-environmental Indicators database	CO ₂ -eq emissions/ha
	Country with high sustainable productivity – Sustainable productivity strong (SPS)	Indicators above combined with no substitution between elements, that is, MIN(MIN(NS, PS, GHG) and TFP) is selected	Index value
	Country with high sustainable productivity – Sustainable productivity semi-strong (SPSS)	Combined MIN and average of indicators above, i.e. AVERAGE (MIN(NS, PS, GHG) and TFP) is selected	Index value
	Country with high sustainable productivity – Sustainable productivity weak (SPW)	Average of indicators above, i.e. (AVERAGE(AVERAGE(NS, PS, GHG) and TFP)	Index value
Exogenous conditions related to structure and intensity of production	Country with high nitrogen fertiliser intensity (NFI)	2015; OECD AEI database	Kg/ha
	Country with high nitrogen manure intensity (NMI)	2015; OECD AEI database	Kg/ha
	Country with high phosphorus fertiliser intensity (PFI)	2015; OECD AEI database	Kg/ha
	Country with high phosphorus manure intensity (PMI)	2015; OECD AEI database	Kg/ha
	Country with high share of cropland in total agricultural land (SC)	2015; OECD AEI database	%

Exogenous conditions related to environmental, innovation, and agricultural policies, and economic welfare	Country with high environmental policy stringency (EPS)	Environmental policy stringency indicator, OECD	Index value
	Country with high R&D expenditures (RDE)	Share of budget expenditures on agriculture R&D as a percentage of agricultural value-added, OECD Statistics and National Accounts	%
	Country with high adoption of innovation (AIN)	Qualitative data in OECD innovation country reviews	OECD expert judgment (scale 1 to 4)
	Country with high total agr. support (TS)	Quantitative data from OECD PSE Database, 2015	EUR/value of production, EUR
	Country with high agr. support based on commodity output (OP)	Quantitative data from OECD PSE Database, 2015	EUR/value of production, EUR
	Country with high level of payments based on input use (IP)	Quantitative data from OECD PSE Database, 2015	EUR/value of production, EUR
	Country with high level of payments, production required (DPPR)	Quantitative data from OECD PSE Database, 2015	EUR/value of production, EUR
	Country with high level of payments, production not required (DPPN)	Quantitative data from OECD PSE Database, 2015	EUR/value of production, EUR
	Country with high share of payments with input constraints (SICS)	Quantitative data from OECD PSE Database, 2015	%
	Country with high gross domestic product (GDP)	Quantitative data from OECD Statistical Database	€/capita

Source: Authors. AEI = agri-environmental indicators. PSE = Producer Support Estimates.

Results and discussion

140. All truth table analyses were run with an inclusion threshold of 0.75. Tables 3.4 and 3.5 present the parsimonious solutions, which reduce the configurations to the smallest number of conditions possible.

141. First the solution for *Sustainable Productivity, Weak* (SPW), is derived. This is followed by *Sustainable Productivity, Semi-Strong* (SPSS) and, finally, *Sustainable Productivity, Strong* (SPS). In this way, one can test how parameter values for the overall fit of selected models (inclusion and coverage) and the model-corresponding countries change when the requirements for countries to count as having a sustainably productive agricultural sector are increased.

142. Table 3.3 presents the full solution for the weak indicator. Please recall that, for this indicator, an aggregation rule is adopted whereby low performance on one environmental sustainability dimension can be substituted for by high performance on another dimension. So as to eventually operationalise sustainable productivity, substitution is also allowed in the second stage between productivity growth and environmental sustainability.

Table 3.3. Solution for the outcome “Sustainable Productivity, Weak”

PI		Incl	Cov.r	Cov.u	m ₁	m ₂	m ₃	m ₄	m ₅	Cases
1	<i>nmi</i>	0.815	0.828	0.004			0.397	0.117	0.242	AU, AT, CA, EE, FI, FR, IT, PL, PT, ES, SE, US
2	<i>SICS</i>	0.647	0.843	0.027	0.464	0.420		0.131		AT, DK, EE, FI, FR, DE, IT, NL, PL, PT, ES, SE, US
3	<i>dppr</i> \wedge <i>GDP</i>	0.883	0.542	0.000		0.119	0.111			AU, CA, DK, DE, NL, SE, US
4	<i>IP</i> \wedge <i>dppr</i>	0.931	0.451	0.026					0.026	PL, SE, US
5	<i>ip</i> \wedge <i>GDP</i>	0.907	0.498	0.000	0.119				0.098	AU, CA, DK, DE, NL
	<i>m</i> ₁	0.673	0.961							
	<i>m</i> ₂	0.673	0.961							
	<i>m</i> ₃	0.797	0.939							
	<i>m</i> ₄	0.648	0.959							
	<i>m</i> ₅	0.797	0.964							

Notes: All conditions are presented in Table 3.2. For example, in that Table NMI refers to high nitrogen manure intensity. Here *nmi* refers to the absence of high nitrogen manure intensity. Same logic applies for other conditions.

143. In total, we find five models with reasonably high figures for inclusion and coverage, but for only two of them, namely *m*₃ and *m*₅, all prime implicants exceed our chosen inclusion cut-off of 0.75. Both of these models exceed this cut-off also on coverage. For purposes of interpretability, these models are restated in one-line sum-of-product form below:²⁵

$$m_3: \quad nmi \vee (dppr \wedge GDP) \leftrightarrow SPW$$

$$m_5: \quad nmi \vee (IP \wedge dppr) \vee (ip \wedge GDP) \leftrightarrow SPW$$

144. While the solution features no essential prime implicants, both models share the absence of high nitrogen manure intensity (inclusion 0.815, raw coverage 0.828). The second and last prime implicant of *m*₃ is given by the conjunction of the absence of a high level of direct payments for which production is required and the presence of a high level of per-capita GDP (inclusion 0.883, raw coverage 0.542). In *m*₅, the second prime implicant consists of a conjunction between the presence of a high level of input payments and the absence of a high level of direct payments for which production is required (inclusion 0.931, raw coverage 0.451), and the third prime implicant consists of a conjunction between the absence of a high level of input payments and the presence of a high level of GDP per-capita (inclusion 0.907, raw coverage 0.498).

145. The key finding from these results is that it is the absence of high nitrogen manure intensity as a production structure-related condition, which is a key driver of good environmental performance in relation to GHG emissions and nutrient surpluses. In relation to the role of policy, agricultural policy contributes positively to sustainable productivity where there is a *low level* of production-related support payments. Country cases included in these pathways are mainly the EU countries, Canada and the United States where

²⁵ “ \wedge ” stands for the logical concept “and”, also called conjunction, “ \vee ” for the logical concept “or”, also called disjunction, “ \leftrightarrow ” for the logical concept “is necessary and sufficient for”, also called equivalence. Finally, if it was the case that not all cases of SPW in a given set of data could be explained, then the equivalence operator would be replaced with the less strong implication operator, “ \rightarrow ”.

agricultural support payments are largely decoupled from production (that is, they belong to PSE category E) or Australia which has low level of agricultural support in every support category. These countries also have a high level of GDP per capita and many of them have strong environmental policy stringency. Denmark, Germany, and the Netherlands achieve the outcome of high sustainable productivity as given by a weak indicator even though in these cases production intensity and structure related condition is not as favorable as in other countries achieving this outcome. On the other hand, the absence of production-related agricultural support and the high share of payments with environmental constraints contributes positively to the achievement of sustainable productivity.

146. A high level of input payments seems to be, at least with respect to the theoretical expectations, counter-productive to the achievement of high sustainable productivity. However, countries belonging to this path (Poland, Sweden, and the United States) do not have the environmentally most problematic input payments, such as fertiliser subsidies, but rather payments for adopting certain technologies and practices, which in many cases may be environmentally friendly ones.

147. Overall, these two best-fitting models (m3 and m5) show that a country can achieve high sustainable productivity if livestock density and thus manure intensity, is low and if agricultural support payments are not coupled to production. Generally, high livestock density per ha of agricultural land, and thus high nitrogen and phosphorus manure intensity per ha of agricultural land, make it very difficult to avoid high nitrogen and phosphorus surpluses and high GHG emissions, and thus to achieve high sustainable productivity. Similarly, high levels of coupled agricultural support payments allow the expansion of agriculture relative to other land use sectors that may have better environmental performance with respect to water quality and GHG emissions, such as forestry and conservation lands.

148. With respect to second outcome indicator, which operationalises a semi-strong concept of sustainable productivity, the models remain exactly the same as for the weak indicator, the only differences consisting of small changes in the overall model and solution fit statistics. For the sake of completion, the solution for it is provided in Table AE.1 in **Annex E**.

149. The complete solution for the third outcome indicator, “Sustainable Productivity, Strong”, is shown in Table 3.4.

Table 3.4. Solution for the outcome “Sustainable Productivity, Strong” (SPS)

PI		Incl	Cov.r	Cov.u	m ₁	m ₂	m ₃	Cases
1	<i>IP</i> \wedge <i>gdp</i>	0.680	0.613	0.000			0.257	EE, PL
2	<i>nmi</i> \wedge <i>gdp</i>	0.700	0.847	0.043		-		EE, FR, IT, PL, PT, ES
3	<i>SICS</i> \wedge <i>gdp</i>	0.656	0.805	0.000	-			EE, FR, IT, PL, PT, ES
4	<i>nmi</i> \wedge <i>ip</i> \wedge <i>SICS</i>	0.719	0.585	0.067			0.229	FR, IT, ES
	m ₁	0.656	0.805					
	m ₂	0.700	0.847					
	m ₃	0.664	0.842					

Notes: All conditions are presented in Table 3.2. For example, in that Table NMI refers to high nitrogen manure intensity. Here *nmi* refers to the absence of high nitrogen manure intensity. Same logic applies for other conditions.

150. In total, three models with reasonably high parameter values for inclusion and coverage are found, which are restated in one-line sum-of-product form below for purposes of interpretability:

$$m_1: SICS \wedge gdp \rightarrow SPS,$$

$$m_2: nmi \wedge gdp \rightarrow SPS,$$

$$m_3: (IP \wedge gdp) \vee (nmi \wedge ip \wedge SICS) \rightarrow SPS.$$

151. The first two models, m_1 and m_2 , feature a single prime implicant: the conjunction of a high share of agricultural support payments with constraints and the absence of a high level of per-capita GDP in the former (inclusion: 0.656; coverage: 0.805), the conjunction of the absence of high manure nitrogen intensity and the absence of a high level of per-capita GDP in the latter (inclusion: 0.700, coverage: 0.847). The third model, m_3 , consists of two prime implicants: the conjunction of a high level of input payments and the absence of a high level of per-capita GDP (inclusion: 0.680, coverage: 0.613), and the conjunction of the absence of high nitrogen manure intensity, the absence of a high level of per-capita GDP and a high share of agricultural support payments with constraints (inclusion: 0.719, coverage: 0.585).

152. Compared to the previous solution under a weak indicator, in which 12 countries achieved high sustainable productivity, under a strong indicator solution only six countries can be classified as sustainably productive. Overall, the three models all emphasise that a certain type of agricultural production structure (low livestock density and thus manure intensity) and agricultural support policy (high share of payments with environmental constraints) are important for achieving a high level of strong sustainable productivity. Although all corresponding countries have relatively low GDP per capita, at least among the set of OECD countries analysed here, many of them have relatively high environmental policy stringency as well as high productivity growth, the combination of which should contribute to achieving strong sustainable productivity.

153. Our research hypothesis was that countries with low level of agricultural support in categories A, B or C are likely to have good sustainable productivity performance (combined productivity and environmental sustainability performance). Our results for the weak indicator (SPW) show that a country can achieve high sustainable productivity if livestock density and thus manure intensity is low and agricultural support payments are not coupled to production. And the results for strong indicator (SPS) again show that certain type of agricultural production structure (low livestock density and thus manure intensity) and agricultural support policy (high share of payments with environmental constraints) are important. Thus, these results support hypothesis.

Conclusions

154. An important policy question for many governments is whether current set of agricultural policies perform well in enhancing sustainable productivity of food and agriculture sector. In this chapter country-level observational data and the fuzzy set QCA are used for assessing the role of agricultural support policies in relation to sustainable productivity. The results support research hypothesis and show that a country can achieve high sustainable productivity if livestock density is low and agricultural support payments are not coupled to production or environmental constraints are attached to them.

155. The findings from this analysis also support ex-ante modelling results obtained in Henderson and Lankoski (2019_[24]) which suggest that in OECD countries, coupled support

policies (market price support and payments based on input use or outputs) are the most environmentally harmful while fully decoupled payments are the least environmentally harmful support policies. However, in addition to the role of policies, our results demonstrate the relatively strong role of production structures and intensity for potential achievement of sustainable productivity.

156. These results seem to imply that agricultural policy reforms through decoupling of agricultural support from production may not solve environmental problems related to production structure and intensity in cases where production intensities are high due to past policies and due to current price ratios provided by markets. Naturally, decoupling of support from production removes intensification incentives provided by policies, but it does not incentivise lower intensity than given by price ratios at markets. Thus, to improve sustainable productivity, countries that have certain production structures and production intensity need to reduce production-related support payments (categories A, B and C) and to add strong environmental cross-compliance criteria to decoupled support payments (categories D and E) in order to minimise harmful impacts of agricultural support policies on sustainable productivity targets.

157. Output and input payments affect both the intensive and extensive margins, whereas coupled direct payments primarily affect the extensive margin. For annual cropping systems, these effects are likely to occur over the short term, as farmers can immediately respond on both the intensive and extensive margins. For livestock systems, impacts, particularly on the extensive margin, may take longer to occur, due to the costly investments needed to expand livestock operations.

158. As regards QCA as a tool for agricultural policy analysis, these preliminary results indicate that it can be useful tool to illustrate key conditions affecting sustainable productivity outcomes. Thus, this methodology seems to be worth pursuing in OECD efforts to analyse policy impacts on agricultural performance, especially if good data is available. For future potential applications of QCA, one could test with similar data a two-step QCA in which so-called 'remote conditions' consist of general policies and production conditions that are fixed from the perspective of the agricultural policy-maker in the short term. These could include general innovation and environmental policies and production structure of the agriculture sector. Remote conditions provide a context for more sector-specific agricultural and agri-environmental policies whose design and implementation can be changed by a given sector policy-maker.

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Annex A. Sustainable productivity index

Total factor productivity (TFP) is estimated by using Törnqvist approximations for Divisia indices. A Divisia index of TFP growth can be defined as the growth in scalar output ($y = f(x,t; \alpha)$), which cannot be explained by the growth in the input quantity index (vector X) over time (t). A simple index method is used because it is otherwise difficult to provide meaningful definitions of real input or real output due to the heterogeneity of outputs produced and inputs used in different time periods or under different policy scenarios. However, it is possible to provide meaningful definitions of input growth and output growth between any two periods of time or between policy scenarios using index number theory. A separate quantity index is calculated for inputs and outputs, and TFP is measured by calculating the ratio between produced output quantity and input quantity. The sustainable productivity index is computed by introducing GHG emissions and nutrient runoff on the input side, capturing use of natural resources and other environmental services as inputs for agricultural production.

Social valuation estimates are used to monetise environmental effects (social costs). Marginal water quality damage from nitrogen and phosphorus runoff is set at EUR 6.8/kg of N-equivalent runoff (Gren, 2001). Phosphorus runoff is converted to nitrogen runoff by employing Redfield ratio 7.2. For GHG emissions, a constant marginal social damage estimate of EUR 30/tonne of CO₂-eq is employed (OECD, 2016).

A Törnqvist index is a discrete approximation to a continuous Divisia index. A Divisia index is a weighted sum of the growth rates of the various components, where the weights are the component's shares in total value. For a Törnqvist index, the growth rates are defined to be the difference in natural logarithms of successive observations of the input (output) components (i.e. their log-change) and the weights are equal to the mean of the factor shares of the components in the corresponding pair of periods (years, if productivity changes are measured over time) or policy scenarios (if productivity changes are measured between policy scenarios).

The estimated input (output) index over time:

$$\ln(Q_t / Q_{t-1}) = \frac{1}{2} \sum_{j=1}^k (S_{jt} + S_{jt-1}) (\ln q_{jt} - \ln q_{jt-1})$$

where Q_t = Divisia quantity index at time t
 S_{jt} = output share of input j at time t
 q_{jt} = quantity of the input j at scenario t
 $j = 1, 2, \dots, k$
 k = the number of outputs

We used constant prices for all inputs and outputs over time and policy scenarios.

Annex B. Clustering procedure for farm-level model

In order to derive stylized regional production systems for bio-economic model, data of the CAPRI database for the year 2012 is employed, considering 23 European countries. Data relate to, for example, regional crop acreage and dairy cow numbers, crop and milk yields, application of nitrogen and phosphorus in chemical fertiliser and manure, value of outputs and production inputs, various GHG emissions and total global warming potential of crop and milk production, ammonia emissions, and feed inputs.

A clustering approach is adopted which allows data to be grouped on the basis of similarity across production technologies on the basis of a set of agricultural production data from the Capri database. The aim is to generate a robust grouping of regions based on production technologies. Production technologies are defined loosely as production sets that could be adequately described using multivariate normal distributions of outputs and inputs. This allows to classify regions on the basis of similarity in production technologies without requiring assumptions on the exact functional form taken by the production technology.

The model-based clustering algorithm from the Mclust (Fraley and Raftery, 2002) library in the R program is used to generate clusters based on the multi-variate normal distribution. Specifically, each k th cluster was associated with an independent multi-variate normal distribution:

$$\phi_k \sim MVN(\mu_k, \Sigma_k)$$

Membership in a group was identified using a probability function based on the likelihood that ϕ_k was representative of observations from region i . Let l_{ijk} represent the likelihood that ϕ_k is the best representation of the i th region's set of production data. The likelihood that region i is a member of group k (L_{ik}) is:

$$L_{ik} = \sum_{s=1}^s l_{isk}$$

$$l_{isk} = \ln \phi_k(X_{is})$$

X_{is} = observed (s) production data for region i

$\phi_k(\cdot)$ = multi – variate normal probability density function

Given j cohorts the probability (P_{ik}) that a region i is a member of group k is then:

$$P_{ik} = L_{ik} / \sum_{k=1}^K L_{ik}$$

The remaining issue is the number of groups which are used to sufficiently identify patterns of variation in outputs and inputs in the CAPRI database. As with the production

technologies, the number of groups is unknown *a priori*; it is also a latent variable. A simple approach to choosing the number of groups is to estimate latent class models for 1 to K groups and to choose the model which generates a good fit. The number of groups is chosen using the Bayesian Information Criterion (BIC) and the Akaike Information Criterion (AIC).

The data used in the clustering algorithm are a subset of CAPRI data and focuses on production output and profit (accounting for prices and input usage). The full set of all variables is not used because clustering algorithms tend to become less stable with higher degrees of dimensionality. The variables used are the yield totals of all crops in each region, the yield totals of dairy production in each region, the land area of dairy relative to crops, and the gross margin of all crops and of dairy production. The latter is chosen to provide a single-dimension measure of farm profitability in each region incorporating the prices they receive for output and the costs and levels of inputs used to produce outputs.

The clustering model was best represented by an 8-component ellipsoidal (allowing for off-diagonal elements in the covariance matrix) and varying-location (different means between components) model. Figure 3.1 presents the means of each variable used in the clustering model for the selected 8-group model. As shown, there is substantial variance between the groups with both high-intensity crop or dairy production regions and low-intensity regions associated with lower gross margins (typically but not ubiquitously).

Annex C. Total Factor Productivity outcomes for farm-level modelling

Table A C.1. TFP under different policy instruments relative to the Baseline

	Cluster 1	Cluster 6	Cluster 7
Baseline	1.00	1.00	1.00
Market price support for crops	0.95	0.98	0.97
Market price support for milk	1.00	1.01	1.08
Payments based on input use	0.99	1.01	1.02
Payments based on current crop area	0.96	0.94	0.96
Payments on current animal numbers	0.95	0.98	1.01
Payments on non-current area	1.00	1.00	1.00

Annex D. Raw data for QCA analysis

Table A D.1. Raw data: Outcomes

Country	Outcomes			
	Productivity, index value	Nitrogen surplus, kg/ha	Phosphorus surplus, kg/ha	GHG emissions, kg/ha
AU	0.01939	20	1	182
AT	0.01407	41	2	2638
BE	0.01864	132	5	7581
CA	0.00812	32	1	1008
DK	0.02754	80	7	3961
EE	0.03834	22	-7	1352
FI	0.01734	49	4	2855
FR	0.02988	42	0	2682
DE	0.01995	82	-2	3986
GR	0.00613	59	0	1541
IE	-0.00285	42	5	4232
IT	0.01906	66	-1	2325
JP	0.02450	178	62	7483
KR	0.01885	222	46	12010
NL	0.03466	189	3	10178
NZ	0.00177	60	8	3607
NO	0.01731	100	10	4555
PL	0.02525	48	2	2052
PT	0.01939	41	5	1818
ES	0.02744	39	4	1445
SE	0.01063	32	0	2267
CH	0.00663	60	2	3943
UK	0.00933	83	5	2445
US	0.01665	28	3	1341

Table A D.2. Raw data: Production structure and intensity related conditions

Conditions: Structure and intensity of production					
Country	Nitrogen fertiliser, kg/ha	Nitrogen manure, kg/ha	Phosphorus fertiliser, kg/ha	Phosphorus manure, kg/ha	Share of cropland from total agr. land
AU	4	8	1	1	0.12
AT	49	61	4	11	0.43
BE	112	172	4	28	0.61
CA	45	9	1	4	0.65
DK	74	99	7	24	0.91
EE	36	23	4	5	0.66
FI	63	46	5	8	0.99
FR	77	61	7	10	0.65
DE	112	77	9	14	0.70
GR	36	58	5	8	0.60
IE	75	106	9	15	0.11
IT	47	65	6	12	0.35
JP	120	133	50	25	0.80
KR	142	172	23	38	0.98
NL	137	221	3	31	0.55
NZ	40	129	11	14	0.04
NO	106	83	10	13	0.83
PL	70	36	9	7	0.76
PT	31	42	6	7	0.32
ES	47	36	10	6	0.52
SE	66	40	6	6	0.85
CH	33	87	4	15	0.26
UK	65	59	7	10	0.35
US	29	26	5	5	0.39

Table A D.3. Agricultural support policy related conditions

Country	Conditions: Agricultural support policy (support payments, EUR / value of production, EUR)						
	Total support	Output payments	Input payments	Direct payments – production required	Direct payments – production not required	Payments with input constraints	Share of payments with input constraints, %
AU	0.018	0.000	0.009	0.001	0.008	0.001	6
AT	0.278	0.081	0.035	0.053	0.109	0.153	55
BE	0.084	0.024	0.011	0.016	0.033	0.046	55
CA	0.089	0.043	0.008	0.028	0.010	0.002	2
DK	0.094	0.027	0.012	0.018	0.037	0.052	55
EE	0.331	0.096	0.042	0.063	0.129	0.182	55
FI	0.480	0.140	0.061	0.092	0.188	0.264	55
FR	0.132	0.038	0.017	0.025	0.052	0.073	55
DE	0.132	0.038	0.017	0.025	0.052	0.073	55
GR	0.268	0.078	0.034	0.051	0.105	0.148	55
IE	0.228	0.066	0.029	0.044	0.089	0.126	55
IT	0.138	0.040	0.017	0.026	0.054	0.076	55
JP	0.461	0.410	0.018	0.002	0.031	0.022	5
KR	0.544	0.489	0.019	0.017	0.018	0.022	4
NL	0.036	0.011	0.005	0.007	0.014	0.020	55
NZ	0.009	0.006	0.002	0.000	0.000	0.000	0
NO	0.869	0.414	0.050	0.403	0.003	0.269	31
PL	0.223	0.065	0.028	0.043	0.087	0.123	55
PT	0.185	0.054	0.023	0.035	0.072	0.102	55
ES	0.141	0.041	0.018	0.027	0.055	0.078	55
SE	0.228	0.066	0.029	0.044	0.089	0.126	55
CH	0.826	0.437	0.025	0.166	0.178	0.347	42
UK	0.139	0.040	0.017	0.027	0.054	0.076	55
US	0.102	0.021	0.029	0.024	0.029	0.057	56

Table A D.4. Raw data: Environmental policy, innovation policy and GDP related condition

Conditions: Environmental and innovation policy and GDP				
Country	Environmental policy stringency, index value	Research and Development, % of value-added	Adoption of innovation, scale: 1 to 4	GDP, €/capita
AU	2.5	1.6	4	41818
AT	3.6	1.3	3	41208
BE	2.1	1.2	2	38602
CA	3.2	1.8	4	39306
DK	4.5	2.1	3	41533
EE	3.6	2.5	4	28067
FI	4.0	1.9	3	37380
FR	2.6	1.1	3	35402
DE	3.6	4.1	4	38698
GR	1.9	0.6	2	30701
IE	2.0	4.2	4	42832
IT	2.1	0.9	2	33966
JP	3.1	1.7	3	32251
KR	3.2	2.7	3	28740
NL	4.1	1.4	4	44393
NZ	2.5	1.6	4	31209
NO	3.8	4.8	3	59190
PL	3.1	0.6	4	20101
PT	2.0	1.7	2	26453
ES	3.6	1.4	2	32514
SE	3.6	1.0	4	39734
CH	3.8	2.1	4	50207
UK	2.7	3.6	4	35877
US	2.8	1.0	4	47503

Annex E. Results for Sustainable productivity, semi-strong (SPSS)

Table A E.1. Solution for outcome SPSS

PI	Incl	Cov.r	Cov.u	m ₁	m ₂	m ₃	m ₄	m ₅	Cases
1	nmi	0.738	0.848	0.000		0.395	0.120	0.234	AU, AT, CA, EE, FI, FR, IT, PL, PT, ES, SE, US
2	SICS	0.569	0.838	0.017	0.459	0.412		0.110	AT, DK, EE, FI, FR, DE, IT, NL, PL, PT, ES, SE, US
3	dppr ^ GDP	0.798	0.553	0.000		0.127	0.100		AU, CA, DK, DE, NL, SE, US
4	IP ^ dppr	0.881	0.483	0.029				0.029	PL, SE, US
5	ip ^ GDP	0.815	0.506	0.000	0.127			0.085	AU, CA, DK, DE, NL
	m ₁	0.598	0.965						
	m ₂	0.598	0.965						
	m ₃	0.712	0.948						
	m ₄	0.572	0.958						
	m ₅	0.714	0.977						