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The role of multi-target policy instruments in agri-environmental policy mixes

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ABSTRACT

The Tinbergen Rule has been used to criticise multi-target policy instruments for being inefficient. The aim of this paper is to clarify the role of multi-target policy instruments using the case of agri-environmental policy. Employing an analytical linear optimisation model, this paper demonstrates that there is no general contradiction between multi-target policy instruments and the Tinbergen Rule, if multi-target policy instruments are embedded in a policy-mix with a sufficient number of targeted instruments. We show that the relation between cost-effectiveness of the instruments, related to all policy targets, is the key determinant for an economically sound choice of policy instruments. If economies of scope with respect to achieving policy targets are realised, a higher cost-effectiveness of multi-target policy instruments can be achieved. Using the example of organic farming support policy, we discuss several reasons why economies of scope could be realised by multi-target agri-environmental policy instruments.

1. Introduction

Agri-environmental measures have been introduced in the European Common Agricultural Policy (CAP) primarily for reducing negative environmental externalities of agriculture. The EU allows members states to choose from a portfolio of different instruments and to set payment levels according to region-specific opportunity costs and necessities. In the current programming period EU Member States allocate on average 30% of their rural development programme budgets towards these schemes (EC, 2012). In Switzerland, agri-environmental direct payments receive about 29% of the all direct payments and 14% of total spending for agriculture (FOAG, 2012).

There is a substantial body of literature analysing specific measures or instruments with respect to environmental effectiveness and economic efficiency (Bakam et al., 2012; Carey et al., 2003; Uthes and Matzdorf, 2013). The importance of targeting and tailoring of policies to achieve maximum effectiveness with a given budget or to minimize spending for achieving the targets set has been stressed by economists and policy makers (OECD, 2007b). It is therefore necessary to compare both environmental impacts and the societal costs of agri-environmental policy instruments with each other in order to provide a basis for economically sound policy design (Pearce, 2005; Primdahl et al., 2010).

The Tinbergen Rule (1956) has been a guiding principle for economists and policy makers for more than 50 years. It is applicable generally across all economic sectors and has been discussed with respect to agricultural policy, waste policy, health policy, energy policy and climate policy (Ahrens and Lippert, 1994; Braathen, 2007; Knudson, 2009). The main statement of the Tinbergen Rule is that efficient policy requires at least as many policy instruments as there are targets. The common interpretation of this rule is to favour single-target policy instruments over broader instruments. Tinbergen's thoughts have also substantially influenced agri-environmental policy (Mann, 2005b). Multi-target policy instruments, in particular cross-compliance (Mann, 2005a) and support for organic farming via direct payments (von Alvensleben, 1998) have been evaluated to be inefficient as their multi-target character seems to contradict Tinbergen's postulate. However, empirical data from evaluation studies is scarce due to methodological constraints (Viaggi et al., 2011) and does not permit the

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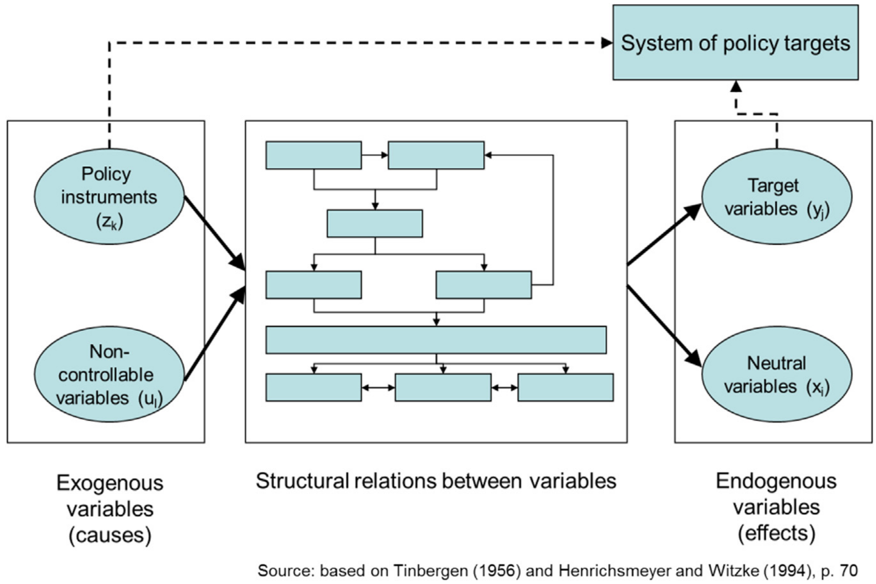

Fig. 1. Targets and instrument links in agricultural policy according to Tinbergen's model.

drawing of general conclusions on the efficiency of multi-target policy instruments.

Thus, the first aim of this paper is to explore how the economically optimal mix between single and multi-target policies can be determined. The second aim is to illustrate advantageous and disadvantageous conditions for multi-target policy instruments in policy mixes and to analyse how multi-target policies integrated in a policy-mix impact cost-effectiveness. We have chosen to use support for organic farming as an example of a multi-target policy, as the organic production standards that are supported by such policies have been developed to address a range of environmental, food and social goals (Schader et al., 2012).

In order to pursue these aims, an analytical linear optimisation model was used. The model simulates the decision-making process from the viewpoint of a rational policy maker, with specified policy targets and a set of instruments to reach these targets, subject to minimisation of public expenditure as the objective function.

In this paper, we provide a brief summary of the theory behind the Tinbergen Rule and clarify its implications for policy mixes and multi-target policies (Section 2). We explain the analytical model to systematically analyse the problem (Section 3). The results of the modelling exercise are presented in Section 4, while Section 5 discusses the model assumptions and results against their degree of realism. Finally, conclusions for science and policy are drawn in Section 6.

2. Tinbergen Rule and agri-environmental policy

In this section, we review the Tinbergen Rule and discuss its relevance for policy mixes and multi-target policies under consideration of economies of scope.

2.1. Review of Tinbergen's model for quantitative policy analysis

Criticising standard policy making for (a) its trial and error approach, (b) the isolated view of single measures (widely ignoring the effects of measures on other aims), and (c) qualitative arguments for changing policies, Tinbergen introduced a quantitative approach to policy making taking into account several policy instruments and targets at once (Tinbergen, 1956, p. 53ff).

With this model, he demonstrated that efficient economic policy needs at least as many independent policy instruments as there are targets. He defined four types of variables: (a) policy-instrument variables which are determinable by a policy maker (with respect to agri-environmental policy this could be taxes on fertilizer or public expenditure for the policy instrument “organic farming area support payments”); (b) target variables which are relevant for the system of policy targets (e.g. protection of natural resources like soil, water, air and biodiversity), (c) variables which are not (or not fully) controllable by the policy maker (e.g. agri-environmental policy does not control inflation or national unemployment rates); and (d) neutral variables which are irrelevant to the system of policy targets. Both policy instrument variables and target variables feed into the system of policy targets (Fig. 1).

Tinbergen modelled the structural relations between these four types of variables as a linear equation system. Each policy target y_j, $j = 1,\ldots,J$ is described by a linear equation of the non-controllable variables, the irrelevant variables and the unknown policy instrument variables z_k, $k = 1,\ldots,K$ that should be determined by solving the equation system. Thus, by the basic properties of linear equation systems, Tinbergen concluded that if the number of independent policy instrument variables equals the number of policy targets, i.e. if the number of unknown variables equals the number of equations in the equation system, his model will have one solution. However, if the number of target variables (i.e. equations) does not match the number of policy instrument variables, the equation system is either over- or underdetermined. If there are more policy instrument variables than policy targets (i.e. equations), the equation system has an infinite number of solutions. In the opposite case, if there are fewer policy instrument variables than policy targets, the equation system only has a solution in accidental cases.[2] Furthermore, Tinbergen argues that even if in this latter case there is an optimal solution, this solution will be inflexible with respect to changes in variables over time that are not directly controlled by the policy maker. This means, if we use a mix of policy instruments for achieving a set of given policy targets, the number of independent policy instruments should

[2] Note that this is only the case for Tinbergen's fixed-target model. Assuming flexible targets, there will be a solution, irrespective of the number of instruments.

Table 1
Possible combinations of policy instruments and policy targets.

Number of policy instruments \ Number of policy targets	1	2 or more
1	A : Single-target policy	C : Multi-target policy
2 or more	B : Policy mix of policy instruments with the same single target	D : Policy mix of single and/or multi-target policy instruments

at least be equal to the number of policy targets. We emphasize that from this general formalism no restriction can be derived that each policy instrument should contribute to the achievement of only one target. Each policy instrument can also contribute to several targets. The policy instruments used need only to be independent from each other, i.e. none of them is a linear combination of the others.[3]

Principally, we can distinguish between cases where one or several policy targets are pursued with either one or several policy instruments. Table 1 shows possible combinations of different numbers of policy instruments and policy targets. In most policy areas, multiple policy targets are pursued simultaneously. Therefore, we can neglect cases A and B with only one policy target to be achieved. If there are two or more policy targets, policy makers have the option to address these by a multi-target policy (C) or by a policy mix of single target and/or multi-target policy instruments (D).

As we have seen above, policy makers should opt for at least two independent policy instruments, if there are two policy targets. Otherwise, Tinbergen's model will most probably have no solution, or if it has one, this will be inflexible. Thus, Option C, i.e. *one* multi-target policy instrument, will most likely *not* achieve multiple fixed policy targets.

However, the most interesting and relevant case in Table 1 is Option D: Multiple policy targets can be achieved by a combination of single- *and/or* multi-target policy instruments, as long as the number of these independent policy instruments is equal to or greater than the number of policy targets. This is a common case for policy makers in European States when they prepare their rural development plans. In Section 4, we will analyse this case in detail in order to find the optimal combination of single and multi-target policy instruments for achieving a set of policy targets.

As Tinbergen emphasizes the differences between policy-mixes of single-target policy instruments and multi-target policy instruments, we discuss in the following paragraphs the most salient considerations regarding (a) policy mixes where several single-target policy instruments are used, and (b) multi-target policy instruments addressing most or all of the policy targets. Finally, we will explain the concept of economies of scope with respect to achieving policy targets, as it will be relevant for interpreting the model assumptions and results in this paper.

2.2. Policy mixes

Policy mixes are defined as combinations of independent instruments for addressing one or more policy targets. The OECD (2007a) stresses that opportunities for mutually enhancing instruments should be exploited. Moreover, instrument mixes provide the possibility of responding flexibly to a changing environmental problem. Finn (2005) describes three circumstances in which policy mixes are applied in policy practice in order to pursue a policy target: Occasionally, policy mixes are implemented because of either a poor scheme design or a lack of clarity about the targets. In other cases, the complexity of the environmental problem results in the implementation of policy mixes *i.e.* when clear causal linkages cannot be established. Furthermore, if several key mechanisms, i.e. what specific actions influences the environmental impacts, are known to be simultaneous driving forces of an environmental problem, these might be addressed by a mix of different policy instruments. Using the example of the European Emission Trading Scheme, Lecuyer and Quirion (2013) show that overlying instruments can be economically justifiable, especially in the case of uncertainty. Also Braathen (2007) stresses that there are good economic reasons for using several policy instruments for addressing a single policy objective. By discussing examples from household waste policy, agri-environmental policy and energy policy, he argues that it is necessary to have a good understanding of the following aspects in order to design effective and efficient policy mixes: (a) the environmental issue to be addressed, (b) the links with other policy areas, (c) interactions between different instruments and (d) the political settings of the country in question. He concludes that there are cases where the environmental effectiveness or the economic efficiency of an instrument mix could be improved by introducing further policy instruments (Braathen, 2007).

Yet, according to Hepburn (2007), parallel implementation of several instruments is problematic, if these are incompatible with each other. If the interactions between different policy instruments are not carefully considered, they may have adverse effects on each other. The OECD (2007a) emphasizes that the risk of mutually conflicting policy instruments increases the more policy instruments are involved. Additionally, overlapping policy instruments ought to be avoided, since these tend to hamper flexibility (OECD, 2007a) and generate unnecessary transaction costs (Dabbert et al., 2004). Thus, from a rational policy maker's point of view, adding a further policy instrument is only justified if transaction costs do not outweigh benefits gained from a more precise and cost-effective policy. Vatn (2005) described this as the 'trade-off between transaction costs and precision'.

2.3. Multi-target policy instruments

Multi-target policies are defined as policy instruments that address more than one target simultaneously. A frequently used example for such a policy is organic farming area support payments (OFASP). Since the early 1990s, European agri-environmental policy offers the option of providing financial support for organic farming

[3] This is the formal way to express independence in the framework of Tinbergen. Framed in a more applied way, independence refers to the fact that policy instruments can be adapted individually without having to change the other instruments at the same time. Thus, e.g. the policy instruments "organic farming support payments" and "prohibition of pesticides" are coupled to each other, as the former entails the latter.

via area payments (Stolze and Lampkin, 2009). Like other voluntary agri-environmental programmes, these payments are intended as incentives for farmers to comply with defined production standards (Häring, 2005). Daugbjerg et al. (2011) showed for the UK and Denmark that organic farming area support payments (OFASP) affect both the number of organic farms and the area under organic farming. As compliance with organic production standards averts negative and provides positive external effects compared to conventional or integrated farming (CRER, 2002; Shepherd et al., 2003), such payments lead to better environmental performance of the agricultural sector as a whole.

However, according to von Alvensleben (1998), organic farming area support payments are inefficient and not economically sound, as they indirectly address many different environmental policy targets. Hence, referring to the Tinbergen (1956) model, von Alvensleben (1998) argues, the policy targets could be achieved more efficiently using more flexible and targeted combinations of various agri-environmental measures.

Mann (2005b) and the Swiss Federal Council (2009) concluded, referring to the Tinbergen (1956) Rule, that multi-target policy instruments are economically inefficient, as the policy targets could be achieved more efficiently by more flexible and more targeted combinations of various agri-environmental measures. Ahrens and Lippert (1994) conclude on the basis of the Tinbergen model that '*a link of policy instruments should be avoided.* […] *A link* [of policy instruments] *results in the simplest case in merging two policy instruments into one*' (Ahrens and Lippert, 1994, p. 152, translated). A similar deduction is made by Mann (2005a, p. 3):

'In economic policy literature, this causal relation came to be known as the Tinbergen-rule. It says that a policy will usually be more efficient if for each target to be achieved at least one instrument is available. Vice versa: Coupling several targets with one instrument will lead to inefficiencies. Such a coupling will lead to a situation where several targets can only be achieved with a particular relation to each other, so that an important degree of freedom is lost. Even if we deal with an instrument which is able to achieve more than one target efficiently, the problem arises at least as soon as changes in the environment require an adoption of instruments'.

Considering our classification in Table 1 above, we see that this criticism applies to Option C, which we discarded as well: it is usually inefficient to achieve several policy targets with one multi-target policy instrument.

Other economists, e.g. Dabbert et al. (2004), argue that even Option C can be legitimate, stressing that an important assumption of the Tinbergen model, namely the absence of transaction costs, is not present in reality. The multi-purpose character of organic agriculture support could increase its cost-effectiveness due to potentially lower transaction costs compared to a set of targeted agri-environmental measures (Dabbert et al., 2004). According to Lippert (2005), reasons for savings of transaction costs due to organic farming support include:

(a) Savings of administrative costs, because fewer AEMs have to be administered per farm.
(b) Generally lower costs of control, because the full prohibition of most synthetic pesticides and synthetic fertiliser is easier to control than thresholds.
(c) Lower costs of control due to a combined control of several attributes.
(d) Lower fixed administrative costs due to the use of existing structures for the establishment of control systems.
(e) Lower intensity of control, to the extent that organic farmers risk their reputation if convicted of non-compliance with regulatory standards.

Therefore, the saved transaction costs may outweigh the savings through having a flexible policy portfolio. While reason (a) and (c) may be applicable to all multi-objective agri-environmental measures, reasons (b), (d), and to an extent (e) as few other agri-environmental measures have a linked market focus, are specificities of OFASP. Economic assessments of agri-environmental policy measures have shown that policy-related transaction costs of policy instruments can amount to a substantial share of total public expenditure for agri-environmental policy (Rørstad et al., 2007). In Switzerland, however, the relative share of transaction costs of the total budget for agri-environmental policy is very small (Buchli and Flury, 2005; Mann, 2003). Furthermore, in two German 'Länder,' empirical data reveal that transaction costs of organic farming support are in a similar range as the transaction costs of a combination of agri-environmental measures (Tiemann et al., 2005).

This debate reflects some general agreement that the Tinbergen Rule may overstate the limitations of multi-target policy instrument. Supporters of such policies, e.g. when arguing for organic farming support, then tend to concentrate on shortcomings in the applicability of the Tinbergen Rule to cases where assumptions, e.g. zero transaction costs, are not realistic. As laid out above, however, this perception of the Tinbergen Rule's judgement on multi-target policy instruments in fact only applies to the situation where several policy targets are pursued with *one* policy instrument. In case of several independent policy instruments, no conclusion on the performance of multi- vs. single-target instruments in such a mix of policy instruments can be derived from the Tinbergen rule.

2.4. Economies of scope with respect to achieving policy targets

A further issue influencing the economic performance of multi-objective agri-environmental measures is economies of scope with respect to achieving policy targets. Based on a concept proposed by Panzar and Willig (1977), economies of scope refer to cases where firms have lower costs when producing several goods jointly instead of producing each good separately. Economies of scope mainly arise due to the joint use of inputs and are seen as a major reason for vertical and horizontal integration of firms. For instance, the fact that a company producing pesticides starts producing seeds can be explained by the concept of economies of scope. Reasons for economies of scope can be of a technical or organisational nature.

However, in agri-environmental policy, even if policies are designed especially to deal with a single environmental problem, they may have substantial side-effects on other environmental problems. For instance, buffer strips along streams and river banks are usually implemented to pursue the targets of both reducing the transfer of nutrients into waterways and increasing the diversity of farmland wildlife. Hence, buffer strips could be conceptualised either as a multi-target policy or a single-target policy with a co-benefit (Feng and Kling, 2005). The support for buffer strips thus realises economies of scope by reducing costs, as two policy targets, namely increased diversity of farmland wildlife and reduced nutrient transfer into waterways, are achieved.

There is empirical evidence of economies of scope with respect to policy targets for environmental policy, in particular for climate and energy policy (Ebi et al., 2006; Huang et al., 2011). For example, Primdahl et al. (2003) analysed environmental impacts of agri-environmental measures and discovered combined improvement and protection effects. Smith et al. (2007) looks at the co-benefits and trade-offs of greenhouse gas mitigation options in agriculture. They identify a large quantity of co-benefits and a lower number of trade-offs. Several of the measures were found to have no trade-offs with other impact categories. Aunan et al. (2004) and He et al. (2010) show co-benefits of climate policy instruments on other environmental policy targets (e.g. level of total suspended particulates and SO_2 in the air) and on health policy targets. These co-benefits are used as an argument in favour of the measure from an economic viewpoint (Aunan et al., 2004).

Co-benefits play a major role also in the context of land use. Kueppers et al. (2004) list potential impacts and propose a land-use decision matrix for evaluating policies in order to consider the co-benefits of policies regarding climate change, environmental impact and socio-economic impacts.

In agricultural policy, the concept of economies of scope has also been raised in the context of multi-functionality (OECD, 2001). It is argued that production of non-commodities such as 'cultural landscape' might cause less costs for society when it is produced jointly with foodstuffs by agriculture (Huber and Lehmann, 2010). Similarly, economies of scope and corresponding cost reductions could also be achieved between different non-commodity outputs (Le Cotty and Voituriez, 2003), e.g. between water pollution reduction and climate change mitigation policies.

3. Model description

We developed a static budget allocation model, based on linear optimisation (Dantzig, 1963) in order to numerically analyse the consequences of using multi-objective policy instruments in agri-environmental policy mixes. The model simulates the decision-making process from a rational policy maker's viewpoint. It consists of a matrix of specified policy targets and single and multi-target policy instruments subject to minimisation of public expenditure as the objective function. The solution procedure determines the optimal mix of single and multi-target policy instruments to achieve the policy targets at least cost in terms of public expenditure.

This analytical model is based on a theoretical model of the key determinants of cost-effectiveness of agri-environmental measures (AEM): policy uptake (implementation of the instruments), environmental effects of the single instruments, and public expenditure per instrument (Schader et al., 2008). The assumptions of the model are kept very simple in order to illustrate the case. It explicitly excludes considerations with respect to transaction costs and 'inconsistency of targets' (Tinbergen, 1956, p. 135), potential implications of these simplifications for the results are discussed in Section 5.

3.1. Model specification

Suppose that a government pursues a set of environmental policy Targets A, B, and C. These targets could, for example, be the reduction of fossil energy use, enhancement of biodiversity, and the reduction of nitrogen leaching. Suppose, further, that the government has set specific quantitative target values and is able to measure the exact level of target attainment as a percentage. The aim of the government is to fully reach Target A, B, and C at least costs or public expenditures respectively.

Employing the basic linear approach from Tinbergen, the question of the optimal combination of policy measures to achieve a number of policy targets is a constrained linear optimisation problem with the following specification.

The government has a set of J policy targets and I policy instruments to achieve the policy targets. The policy targets are characterised by target values y_j, $j = 1,\dots,J$ for several environmental indicators, such as energy consumption per ha, numbers of species per agricultural land ha or tons of nitrogen surplus per ha reduced. These target variables are coded in such a way that higher levels are always better for the environment (thus, for example, if the policy target is a low level of eutrophication, then the indicator is eutrophication reduction). We assume baseline levels for these environmental indicators without policy instruments B_j.

Normally all economic variables show at least minor dependencies on the other figures due to general interdependencies in the economic system. Nevertheless, let us assume that it was possible to pursue each of the targets using a single-target agri-environmental measure (AEM_A, AEM_B, AEM_C) without side effects on other policy targets for this exemplary modelling exercise, as this illustrates the ideal case of a single-target policy instrument. This assumption will not affect the validity of the model results but will help underline the most important conclusions that can be drawn from the model's results.

The policy instruments are characterised by costs and effects (policy outcomes) per unit of implementation. Let the unit of implementation be "hectares under the agri-environmental measure". The cost are then defined as "payment levels per ha" PL_i, $i = 1,\dots,I$, for instance for payments per ha extensively managed grasslands. Each policy instrument i contributes to achieving the target value y_j of the environmental indicator j by its effects of E_{ij} per unit implementation. Thus, E_{ij} can and will be 0 for several targets j for each policy instrument i.

Additionally, assume a multi-target policy instrument (AEM_D) that is able to contribute to all three policy targets simultaneously, but that is also less cost-effective with respect to individual policy targets. This assumption fits, with the existing empirical data of support payments for organic farming in European agri-environmental schemes, as these are known for (a) positively influencing all of the above environmental impacts (Mäder et al., 2002; Schader et al., 2012; Tuomisto et al., 2012), but (b) are not as cost-effective as single-target policy instruments (Jacobsen, 2002; Tiemann et al., 2005).

The values of each environmental indicator E_J , realised by implementing policy instruments $i = 1,\dots,I$ on PI_i ha of land (PI_i is the "policy implementation level" of policy instrument i) are:

$$E_j = \sum_{i=1}^{I} E_{ij} \mathrm{PI}_i + B_j \tag{1}$$

The necessary public expenditure PE to cover the total costs for the government is then determined by the payment levels PL_i and the respective policy implementation level PI_i:

$$\mathrm{PE} = \sum_{i=1}^{I} \mathrm{PL}_i \mathrm{PI}_i \tag{2}$$

The goal of the government is to achieve all targets at least costs, i.e. to minimize PE subject to the constraint that $E_j = y_j$, $\forall_j = 1, \dots, J$:

$$\min_{\mathrm{PI}_i} = \sum_{i=1}^{I} \mathrm{PL}_i \mathrm{PI}_i \ \text{ s.t.} \quad E_j = y_j \tag{3}$$

For the following discussion, it is advantageous to define the relative target achievement by a target attainment index for each policy target: $TAI_j = E_j/y_j$, expressed as a percentage. Using Eq. (1), TAI_j can be expressed as the sum of the initial state of target attainment $IS_j = B_j/y_j$, and the cumulative impact of the policy instruments on Target j: $\sum_{i=1}^{I} E_{ij} PI_i / y_j$.

Given the coding of the target indicator variables described above, full target achievement is characterised by $TAI_j = 100\%$ and the baseline without policy instruments B_j is smaller than the target value y_j. Target attainment indices greater than 100% are possible to achieve in the model, but are seen as neither more positive nor negative in terms of welfare, than a 100% target attainment.

Table 2
Assumptions on effects and payment levels per hectare for different policy instruments for the illustrative model.

Policy instrument	Effect on Target A	Effect on Target B	Effect on Target C	Payment level
AEM_A	2	0	0	1
AEM_B	0	2	0	1
AEM_C	0	0	2	1
AEM_D	1	1	1	1

For further analysis, we numerically implement this model to investigate the performance of a multi-target policy instrument in comparison to single-target policy instruments. The model was implemented in GAMS.[4] We assumed a situation with three policy targets, namely (A) the reduction of fossil energy use, (B) the enhancement of biodiversity, and (C) the reduction of nitrogen leaching. We further assume that initial target attainment IS_j is specified to be 50% for Targets B and C. This means that in the initial state, i.e. before the policy mix is implemented, already 50% of each of those two targets have been achieved (e.g. through policies in former periods of time).

The assumptions about environmental effects and payment levels of each policy instrument are presented in Table 2. Each of the single-target AEMs (AEM_A, AEM_B, AEM_C) addresses a specific target and does not affect the other two targets. On the contrary, the multi-target AEM_D addresses all targets at once, but is less effective per unit of cost in addressing each single target than the respective single-target measures.

3.2. Sensitivity analysis

We tested the following assumptions with a sensitivity analysis.

3.2.1. Variable distance to Target A

The model was run with different specifications of the initial attainment for Target A varying from 0 to 100% in order to analyse the model response to changes in the policy environment that are not controllable by policy makers. This captures the fact that a policy mix has to be flexible in order to respond to changes in the initial environmental state.

3.2.2. Variable specification of costs, effects for organic farming support payments

A key determinant for the model is the specification of cost-effectiveness of the policy instruments (AEM_A, AEM_B, AEM_C, and AEM_D) in consideration of all relevant policy targets. As there are no generalizable figures for the effectiveness of organic farming area support payments and specific AEMs, we tested alternative specifications of costs and effects in sensitivity analysis. Eq. (4) calculates the average cost-effectiveness of each policy instrument ACE_i by dividing the average effects on the targets,[5] by the payment levels[6] of each policy instrument. Thus, contrary to cost-effectiveness of a policy instrument regarding a single target, ACE_i reflects the average cost-effectiveness of a policy instrument regarding all relevant policy targets. ACE_i is the principal indicator for comparing the different specifications presented in Section 4.3.

$$ACE_i = \frac{\frac{\sum_j E_{ij}}{J}}{PL_i} \tag{4}$$

3.2.3. Variable number of policy targets

The number of agri-environmental policy targets in real policy decision-making problems is likely to be higher than three. For instance, the Swiss government defined 12 environmental targets for the natural resources biodiversity and landscape, climate and air, water, and soil (Aeschenbacher and Badertscher, 2008). Not all multi-objective policies have positive impacts on all environmental indicators, however there are examples that come close to such characteristics. According to Schader et al. (2012) and Shepherd et al. (2003) organic agriculture support is likely to have a positive effect on most of these targets. Thus, if the cost-effectiveness of OFASP was analysed for Switzerland using empirical data, it would be necessary to take into account all policy targets and the respective agri-environmental measures addressing these for a full coverage of the problem.

4. Results

4.1. Model run with equal distance-to-target for all policy targets

If the model described in Section 3 is run with initial state (IS) for each target being 50%, the optimal solution is not to implement any of the single-target agri-environmental measures, but only the multi-target AEM_D. Despite there being a single-target AEM for each target that is more cost-effective than the AEM_D, the model regards AEM_D as more efficient. However, looking at Table 2, it becomes clear that if all policy targets are considered at the same time, AEM_D is more cost-effective.

This result is driven by the following dynamics based on Table 2: If no target is reached at the beginning, AEM_D is implemented until the first target is reached, as it is more efficient than implementing the three targeted measures together (1 unit cost for 1 unit improvement in each of the three targets with AEM_D vs. 1.5 units cost for the same improvement with three targeted instruments).

4.2. Model run: with variable distance to Target A

However, in reality we cannot expect to have a policy measure which will allow us to exactly fill our gap between policy target and initial state. To simulate this situation, we varied the initial state for Target A as part of our sensitivity analysis. Fig. 2 shows the optimal implementation levels[7] (left y-axis) for the single-target agri-environmental measures (AEM_A, AEM_B, AEM_C) and the multi-target agri-environmental measure (AEM_D), depending on the variable initial state (IS) of target attainment for Target A. the implementation levels are displayed as dashed lines in the lower part of the diagram. Along the x-axis, 100 model runs are shown with IS being 0–100%, while the initial states regarding Target B and C are fixed at a target achievement of 50%.

In this example, the model optimisation algorithm starts from a situation where no target is reached. As described above, AEM_D is thus implemented to achieve environmental impacts until one of the targets reaches a target attainment index of 100. Starting with zero implementation of A, this is achieved for B and C at the same time. The remaining gap in target attainment of Target A is then filled by the specific policy measure (AEM_A) as this is more efficient

[4] General Algebraic Modelling System, GAMS Development Corporation, 1217 Potomac Street, NW, Washington, DC 20007, USA

[5] For reasons of simplicity, we assume equal weights for each target here. But principally, different weights for targets, as it is usually done in multi-criteria analysis, could be included here.

[6] We assume policy-related transaction costs to be zero here. The issue of transaction costs is discussed in Section 5.

[7] "Optimal" in this case means combinations of instruments that lead full achievement of all targets at least cost.

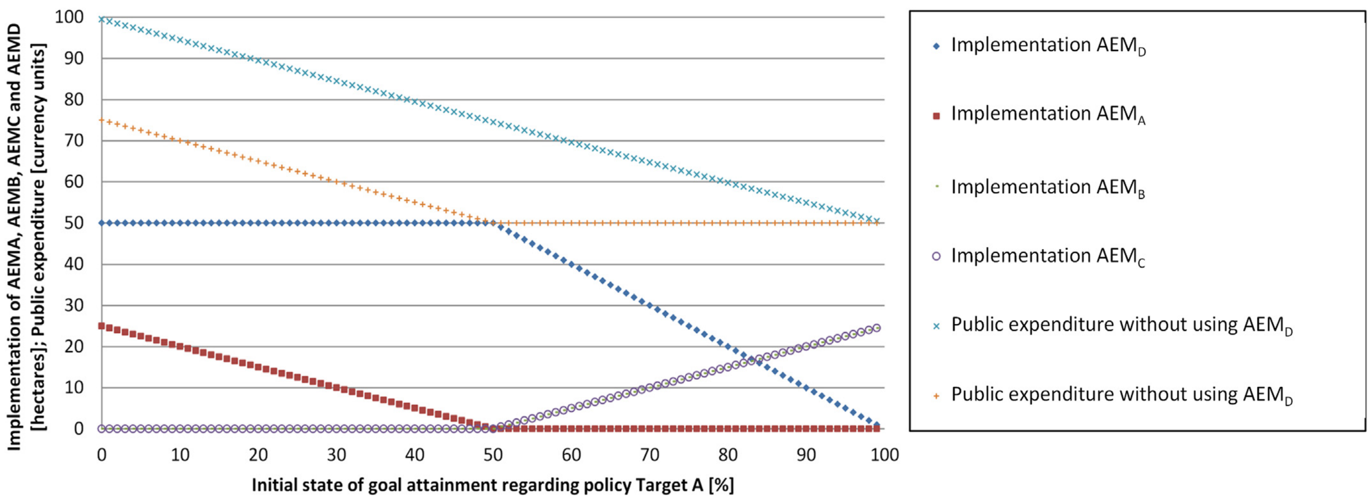

Fig. 2. Optimal implementation of AEMs and the resulting public expenditure with and without use of AEM_D with variable initial states of target attainment for Target A.

then implementing AEM_D on more hectares. In addition, the fixed target prevents additional implementation of AEM_A. As long as the initial target attainment of A remains below 50%, the dynamics remains the same, with decreasing levels of A needed. At 50% initial attainment for A, only AEM_D is implemented (cf. above). For initial attainment levels of A greater than 50%, AEM_D is implemented till the target for A is achieved, the remainder in the targets for B and C can then be reached either with AEM_D or AEM_B and AEM_C together (both cost 1 unit to achieve 1 unit in each target). Under the assumption of fixed targets, AEM_B and AEM_C have to be chosen, as otherwise the target for A would be surpassed.

With decreasing distance-to-target of Target A, the total public expenditure goes down until the IS_A has reached 50%. For IS_A between 50 and 100% there are no more budget savings achievable. If the model was run without AEM_D in the portfolio of agri-environmental measures, we get a continuous decrease in public expenditure with IS_A rising from 0 to 100%. This shows that if policy makers decide not to use multi-objective policy AEM_D, they end up with higher public expenditure if the underlying assumptions of this model are given. So, the distance between both public expenditure curves represents the budget savings due to inclusion of AEM_D in the policy mix, in each of the 100 model runs (Fig. 2).

For instance, the public expenditure for the optimal policy mix, when initial attainment of Target A is 0% would be 75. However, if AEM_D would not be used, i.e. if the targets had to be addressed merely by the single-target AEMs, a public expenditure of 100 would be required. Thus, the potential budget saving for including AEM_D in the policy mix would be 25, equivalent to 25% of the total spending on the policy Targets A, B, and C.

Hence, the extent to which AEM_D is part of the optimal solution depends on the relation of the distances between the initial state and the policy target for the different policy targets and on the relative costs between the instruments to provide one unit target achievement. If the distance-to-target is equal for each policy target, then the model results in the sole implementation of AEM_D (Fig. 2), due to the symmetry in costs and target attainment contributions of the policy instruments considered. If the distance-to-target becomes greater for one target than for the others, the remaining gap in target attainment left by AEM_D is closed by implementing the relevant targeted AEM addressing the respective policy target (in Fig. 2 this is AEM_A). At the same time, the budget share of AEM_D goes down if Target A has a lower distance-to-target than the others.

4.3. *Variable specification of costs, effects and the number of policy targets*

As it was shown in the previous Section, AEM_D is part of the optimal solution and thus of the resulting efficient policy mix. Its average cost-effectiveness is higher than for the single target policies, although the cost-effectiveness of AEM_D regarding single targets is lower. But how much lower can the cost-effectiveness of multi-target policies regarding single targets be, until AEM_D is no longer part of an efficient policy mix?

Based on the model results, this can be derived mathematically for Eq. (4), outlined in Section 3: The average cost-effectiveness of a multi-target policy instruments (ACE_{multi}) should not be less than the average cost-effectiveness of the single-target policy instruments (ACE_{single}) divided by the number of policy targets J (Eq. (5)).

$$ACE_{multi} \geq \frac{ACE_{single}}{J} \tag{5}$$

In our case of three policy targets, AEM_D is the optimal solution instead of the individual AEMs, provided that the cost-effectiveness of the targeted AEMs regarding the single targets does not exceed three times the cost-effectiveness of AEM_D. If the cost-effectiveness of AEMs is more than three times higher than of AEM_D, the optimal policy mix consisted of AEM_A, AEM_B and AEM_C only. Hence, AEM_D payments can be up to 66% less cost-effective than targeted AEMs and still provide the most efficient solution. Correspondingly, AEM_D payments may be up to 66.6% more expensive per unit (e.g. ha of land under the agri-environmental policy) and still be more efficient.

4.4. *Variable specification of policy targets*

If more than three policy targets are included in the model and the cost-effectiveness relation between AEM_D and the other policy measures is kept constant, the optimal share of AEM_D as a proportion of total public expenditure increases correspondingly.

Table 3 shows the relation between ACE_{multi} and ACE_{single} for 1–12 policy targets. For instance, if we have 12 different policy targets, then the average cost-effectiveness of the multi-target policy instrument ACE_{multi} must not be less than 8.3% of the cost-effectiveness of single-target policy instruments ACE_{single} for ACE_{multi} to be part of the efficient policy mix.

Table 3
Margin of relation between the average cost-effectiveness for multi (ACE_{multi}) and single (ACE_{single}) target policy instruments depending on the number of policy targets (J) before multi-target measures become inefficient.

J	ACE_{multi}/ACE_{single}
1	100.0%
2	50.0%
3	33.3%
4	25.0%
5	20.0%
6	16.7%
7	14.3%
8	12.5%
9	11.1%
10	10.0%
11	9.1%
12	8.3%

This shows that ACE_i is the relevant decision parameter for a policy maker, for deciding whether to include a policy instrument in a policy mix. This implies that if policy mixes are designed, this should be done in view of all relevant policy targets, instead of looking at the cost-effectiveness of instruments regarding single targets.

Thus the model results numerically illustrate that AEM_D can in fact be a part of an efficient solution for addressing environmental problems, not as a sole instrument, but as a complementary instrument alongside other measures. The modelled optimal budget share allocated to AEM_D depends on the relative distance-to-target of environmental categories before applying the instruments and the effectiveness and costs of the AEM_D relative to the single-target policy instruments.

5. Discussion of the modelling results

The following questions arise from these results: Are the assumptions made likely to be present in reality? How would our main conclusions regarding the role of multi-objective policy in agri-environmental policy mixes be affected by changed assumptions? Which conditions foster or hinder the use of multi-target policy instruments? In which situation should policy makers allocate more or less funds to multi-target policy instruments?

We discuss these questions by looking at the main assumptions of the model as follows: (a) the number of policy targets, (b) the specification of cost-effectiveness of the AEMs, (c) absence of policy-related transaction costs, d) trade-offs in multi-objective policies, (e) the existence of economies of scope with respect to policy targets, (f) the initial states of target attainment, and (g) the choice of the fixed instead of flexible target model. In order make the discussion more tangible we discuss the above questions using organic farming area support payments (OFASP) as an example for AEM_D as implemented in almost all EU Member States.

(a) Number of policy targets

As shown in the sensitivity analysis, the number of policy targets influences the lowest value that the average cost effectiveness (ACE) of the multi-target policy instrument can take before it is redundant in a mix with single-target instruments. As in most European contexts the number of agri-environmental policy targets is at least eight (e.g. Aeschenbacher and Badertscher, 2008; European Commission, 2014), the marginal relation between the cost-effectiveness of ACE_{multi} and ACE_{single} that renders ACE_{multi} part of the efficient policy mix below 12.5%.

(b) Specification of cost-effectiveness of the AEMs

It is a complex undertaking to derive empirical figures for environmental impacts of different AEMs at a representative scale, as the environmental impacts of AEMs vary substantially among farm types, regions and even single farms. Furthermore, site-specific measurements are costly, impact assessments methods lack harmonization and environmental models often rest on uncertain assumptions. Moreover, the fundamental evaluation bias (Frondel and Schmidt, 2005), i.e. that the same farm cannot be observed with and without the policy (the counterfactual), requires additional statistical tools (e.g. matching methods).

Nevertheless, as far as our example for a multi-target policy instrument, organic farming area support payments, are concerned literature suggests that a) there are substantial positive environmental impacts of organic agriculture (Mäder et al., 2002; Shepherd et al., 2003), and b) if only one outcome is sought, the costs for deriving single environmental impacts with organic farming are higher than those of targeted measures, as farmers have to comply with a bundle of requirements instead of only one requirement (Uthes et al., 2009; Ziolkowska, 2008). Therefore, our conservative assumption that the cost-effectiveness for one policy target of single-target policy instruments is twice the cost-effectiveness of multi-target policy instruments like organic farming area support might be justified. However, Osterburg and Runge (2007) and Schader et al. (2013) stress that the cost-effectiveness of AEMs varies substantially. Therefore, to design an efficient policy mix, a region-specific analysis of the cost-effectiveness of available policy instruments is required to specify Eq. (5) as valid for a multi-objective policy instrument in a given context or not.

(c) Absence of policy-related transaction costs

A simplifying assumption of the model presented in this paper is the absence of policy-related transaction costs (e.g. costs of inspection, control and administration). Following the argumentation by Dabbert and Häring (2003), the use of multi-target policies instead of single-target policies can reduce transaction costs of the agri-environmental policy mix. However, it is obvious that the inclusion of organic area support in the policy mix, in addition to AEM_A, $AEM_{B,}$ and $AEM_{C,}$ causes additional transaction costs. On the other hand, if OFASP is introduced one of the other three policy instruments can be dropped, as three independent policy instruments are sufficient to reach three targets. According to Buchli and Flury (2005), most of the transaction costs of OFASP will be borne by the farmer and thus ultimately by the consumer, rather than by public administration. Nevertheless, the transaction costs need to be subtracted from the cost savings due to including organic farming support in the policy mix (for detailed calculations for Switzerland see Schader (2009)). However, a potential reduction in transaction costs in case one targeted policy instruments is abandoned needs to be taken into account as well.

(d) Trade-offs in multi-objective policies

It is important to note that multi-objective policies might involve trade-offs in the achievement of different environmental targets. For instance with respect to organic area payments, there might be a trade-off between policy targets such as increasing productivity (negative effect) and increasing biodiversity (positive effect). However, trade-offs between policy targets are also likely to occur for single-target instruments (Braathen, 2007; Knudson, 2009; Smith et al., 2007). These trade-offs have to be taken into account. However, this does not contradict the main results of the model, as ACE is composed of all policy targets J and negative impacts could be captured by some decrease in ACE.

(e) The existence of economies of scope with respect to policy targets

If Eq. (5) is fulfilled, we can speak of 'economies of scope with respect to achieving policy targets' (see Section 2 for explanations). But what could be reasons for such economies of scope when implementing multi-target policy instruments compared to single-target policy instruments? In the following, we deduce on the basis of our example "organic area support payments" three areas which might contribute to economies of scope.

- *'Fit' of policy-instrument*: uptake levels of a multi-target policy instrument may be induced by farm-level restrictions e.g. due to the regulatory framework of organic farming (Council Regulation (EC) No 834/2007), regarding general farming intensity, fertiliser purchase, or stocking density. In this case, the regulatory framework facilitates the 'fit' of the agri-environmental measures with extensification of production being the connecting element between the regulatory framework within which the farm already operates and the environmental measure. Furthermore, this 'fit' of the policy instrument may also be supported by the farmer attitudes. Indeed, several authors (Jurt, 2003; Stotten, 2008) found different attitudes of organic farmers towards nature conservation compared to conventional farmers.
- *Synergistic effects*: synergistic effects might contribute to economics of scope due to different reasons:
  a. *Synergistic effects might be due to synergies between societal and private benefits*: consumer demanding specific food attributes (e.g. animal welfare friendly production) are willing to pay a price premium for food which provide these attributes (Lagerkvist and Hess, 2011; Napolitano et al., 2007; Zander et al., 2013). For example, organic products deliver additionally to the societal benefits rewarded through agri-environmental measures (organic farming area payments) a private benefit as reflected in consumers' demand for organic products (Stolze and Lampkin, 2009). Thus, there is a synergy of private and societal demand. Specific agri-environmental measures, on the contrary, so far hardly generate consumer demand and willingness to pay a premium price. Thus costs for management restrictions of single agri-environmental measures must be fully covered by the society (Schader, 2009). It is necessary to keep rewarding farmers' response to societal and private demand separate: response to consumer demand resulting in market benefits reflect the entrepreneurial activities of the supply chain actors and should therefore not be attributed to providing e.g. public good as response to societal demand expressed through agri-environmental policies (Lampkin and Stolze, 2006).
  b. *Synergistic system effects*: according to Niggli et al. (2008), the system approach of organic farming, e.g. the combination of many different production rules, may induce on synergetic environmental effects additional to the effects of each single restriction. For instance, while both a ban on pesticides and the use of traditional, resistant fruit varieties may be inefficient as single measures, the combination of both measures may perform well economically.
- *Transfer efficiency*: Dabbert and Häring (2003) bring forward the argument of lower transaction costs which go along with a lower number of instruments and less specific instruments could improve transfer efficiency. They argue that a support of organic farming within agri-environmental policy should be granted 'where the likelihood is low that the costs of missing a target are lower than the potential savings of transaction costs. This may be the case in particular where a broad improvement of the state of a high number of environmental indicators is aimed at. If there are only specific environmental aims to be achieved, it appears to make sense to introduce specific instruments within conventional farming (Dabbert and Häring, 2003, p. 103).

(f) Initial state of target attainment

The initial state of target attainment was varied in the sensitivity analysis. The more the relation of distances of the initial states to the targets differs from the relation of the effects to expected from the multi-target policy instrument, the less important is the role of the multi-target policy instrument within a policy mix. As we have learnt from the model exercise, it was preferable to use OFASP as a policy instrument until one of the targets was fully reached. On top of that, the remaining targets were achieved using single-target agri-environmental instruments (AEM_A, AEM_B, AEM_C). Thus, multi-target policy instruments play the most important role if strong differences between initial states and target attainment for all environmental indicators are present.

(g) Tinbergen's fixed target approach

Finally in this discussion, it should also be emphasised that, in order to reduce the complexity of the question and to stay in line with Tinbergen's (1956) original fixed target approach, the upper bound of '$TAI = 100\%$' was established. However, theoretically the constraint could also be defined as $TAI \geq 100\%$, if further environmental effects are admitted (flexible targets), which is likely for most environmental indicators. A model formulation with flexible targets would also be justified if policy makers are not able to define a clear quantitative policy target, e.g. due to a high degree of uncertainty of the environmental impacts of the selected indicators. In this case, support via multi-target policies could even be efficient as a single-target measures, as the higher cost-effectiveness of a multi-target policy may outweigh the costs of exceeding the set target (cf. the remarks in Section 4).

6. Conclusions

This paper clarifies the understanding of the Tinbergen Rule and the implications this rule has for agri-environmental policy. The main statement of the Tinbergen Rule is that efficient policy requires at least as many independent policy instruments as there are policy targets. However, the Tinbergen Rule does not imply that coupled policy instruments are per se inefficient. Neither does it advise policy makers to abolish multi-target policy instruments.

Rather, from the general analysis and the results of our analytical linear optimisation model, new insights could be gained regarding the role of multi-target policy instruments within a policy mix. The model demonstrates that multi-target policy instruments can be an efficient policy instrument in a policy mix, provided the assumptions of a higher overall cost-effectiveness regarding the sum of all policy targets are met. This assumption implies that there are 'economies of scope' from implementing multi-target policy instruments. Based on our example of organic area payments, we identified three reasons for economies of scope of multi-target policy instruments: 'fit' of policy instrument, synergistic effects and transfer efficiency

Thus, the Tinbergen Rule is a valid and important principle for policy makers but it cannot be used as a knock-out criterion against multi-target policy instruments, particularly if economies of scope with respect to policy targets are likely. Instead, the consideration of multi-target policy instruments in policy mixes can lead to significant budget savings if their average cost-effectiveness over all policy targets is not lower than the average cost-effectiveness of targeted instruments (i.e. without any side effects on other targets) divided by the number of policy targets. Such a use of multi-target policy instruments in policy mixes does not contradict the Tinbergen Rule. The model analysis suggests implementing policies with a large number of co-benefits in agri-environmental policy in order to increase the overall cost-effectiveness of a policy mix. On the other hand, policy instruments that cause substantial trade-offs with other policy targets should be avoided where possible.

The typical role of multi-target policy instruments within a policy mix lies in providing a basic improvement with regard to many different targets. With each target achieved by this multi-target policy, its relative cost-effectiveness compared to single measures decreases. As soon as the combined cost-effectiveness of single-target policy instruments is higher than that of the multi-target policy, the targeted single target policy instruments need to be used to specifically address the remaining targets. Consequently, the question of the cost-effectiveness of multi-target policy instruments needs to be assessed for each specific country or region on the basis of empirical quantitative economic analysis.

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