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APPLICATION OF A FAIR-DIVISION ALGORITHM TO EU RURAL DEVELOPMENT FUNDS ALLOCATION IN POLAND

Abstract. The allocation of rural development budgets remains problematic due to multiple political measures, diversified groups of potential beneficiaries and difficulties in quantifying the effects of rural development policy. The emerging question is how to support the decision-makers in allocating rural development budgets so as to minimize conflicts of interest among stakeholders and ensure a fair allocation of resources. Therefore, the objective of this paper was to demonstrate that a fair-division algorithm proposed by Moulin (2003) may be effectively applied to allocate rural development budgets, as illustrated by the example of the Polish Rural Development Program. The results show that the procedure allocates the total budget among the program's measures in a reasonable way. It reflects importance of measures, as rated by the beneficiaries, and the options for fund absorption. Moreover, as the procedure objectifies the decision process, it should improve the programs' acceptance among stakeholders.

Keywords: fair division, rural development, budget allocation

INTRODUCTION

The concepts associated with fairness have recently received considerable attention among political scientists and economists. The importance of fairness in resource allocation decisions was discussed extensively by Baumol (1986), Elster (1992), Fleurbaey (2008) and Le Grand (1991). According to Hougaard (2009), the need for fair allocation is a key rationale behind the theoretical investigation of allocation rules.

Brams and Taylor (1996) provide several definitions of fairness, based on properties such as proportionality, envy-freeness, equity, and efficiency. Moreover, they prove that tradeoffs between these notions are inevitable in constructive fair-division schemes[1]. According to Linder and Rothe (2016), fairness valuation criteria also include exactness, equitability, super envy-freeness, and super-proportionality. Moulin (2003) provides the following four principles of fairness, not exclusive of one another: compensation, reward, exogenous rights and fitness.

Based on the above properties, a vast number of fair-division algorithms were developed to enable the allocation of different types of (both divisible and indivisible) goods, as well as homogenous and heterogeneous goods. Cooper et al. (2006) argue that adding fairness

[1] Some conflicts between fairness conditions are presented in Brams et al. (2000) and Brams (2011).

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to interactions between policymakers and households is a way of encouraging citizen participation in policy programs. Thus, the use of fair-division algorithms to solve real-life policy problems seems to be most suitable for policy programs which require participation from the public. This is the case for the EU rural development policy where potential beneficiaries apply for coverage under different measures of rural development programs, and the outcomes depend entirely on the beneficiaries' commitment.

This issue was already considered by Kiryluk-Dryjska (2014) and Fragnelli and Kiryluk-Dryjska (2017). They analyzed the applicability of Brams and Taylor's fair-division algorithm, bankruptcy rules and relevance factor measures in the budgeting procedure of rural development programs, using the 2007–2013 Polish Rural Development Program (2007–2013 PRDP) as an example[2].

Poland is one of the greatest beneficiaries of the rural development policy covered by the EU Common Agricultural Policy. In 2004–2013, the total structural support for Polish Rural Development Programs went beyond EUR 22 billion, while the budget for the current PRDP (2014–2020) amounts to EUR 13.5 billion. The budget is allocated at national level among political programs (measures). However, because it is difficult to quantify the effects of rural development policies, budget allocation remains a problematic issue.

The main objective of this paper is to show how the uniform gains procedure – a fair-division scheme presented by Moulin (2003) – can be constructively applied in the allocation of development policy budgets. For reasons of comparability with earlier studies, the example of 2007–2013 PRDP is also used.

The outline of this paper is as follows. First, a general methodological framework for the uniform gains procedure is provided, and a method is proposed to adjust it to the allocation of rural development resources. Next, the solution is applied to solve a practical problem of budget allocation under a rural development policy in Poland. Finally, this paper concludes with a discussion on potential limitations and practical problems that may arise in the application of fair-division procedures, and compares this approach to those previously described in the literature.

METHODOLOGY

In the simple model of fair distribution, there is a given amount t of a commodity to be divided among a given set of agents, and each agent i is endowed with a claim x. The problem is that the available resource t differs from the total x of claims.

$$t \neq x_N = \sum_i x_i$$

If t is smaller than x_N, there is a deficit; otherwise, an excess exists[3]. The normal rules of the *uniform gains procedure* for deficit specify that agent i receives either a common share λ or his claim x, whichever is smaller[4]. The common share is computed by solving the equation below:

$$\sum_N \min\{\lambda, x_i\} = t$$

The Moulin's algorithm (Moulin, 2003) to compute the uniform gains solution works as follows:

Divide t in equal shares and identify agents whose claims are on the 'wrong' side of t/n (if a deficit exists, this means agents with $x_i \leq t/n$). Satisfy these agents' claims x_i, decrease the resources accordingly, and repeat the same computation for the remaining agents using the remaining resources.

In the case of a deficit, the algorithm for computing the uniform gains solution reveals that the share of agent i must be at least t/n or x_i, whichever is smaller: $y_i \geq min\ \{x_i, t/n\}$. Indeed, an agent who is on the 'wrong' side of the t'/n', at any stage of the algorithm where t' units remain to be shared among n' agents, receives $y_i = x_i$. Moreover, the sequence of per capita shares t/n, t'/n', t''/n'' is nondecreasing. This is because at each step, the claims of the agents who are dropped are below the per capita share. Therefore, an agent who always remains on the right side of t'/n' receives no less than t/n.

In this paper, the above algorithm is adjusted and applied for the allocation of funds under the 2007–2013 Polish Rural Development Program. The Program was composed of 18 measures with a total budget of EUR 15,723.8 million. In order to divide the total budget among program measures with the uniform gains procedure, it was assumed that – with regard to upper and lower bounds for each measure – the claims reported under

[2] The literature also indicates linear programming as another approach to supporting the budgeting process for rural development programs (Kirschke and Jechlitschka, 2002; 2003 and Schmid et al., 2010).

[3] Because the budget allocation is a deficit problem, this paper uses the deficit case scheme.

[4] The procedure for excess is simply a reverse of that used for the deficit problem.

Table 1. Lower and upper bounds for measures under the 2007–2013 PRDP (EUR million)

Measure	Lower bound	Upper bound
Training for persons employed in agriculture and forestry	4.8	48.0
Setting up of young farmers	52.0	520.0
Early retirement	1,880.0	4,800.0
Advisory services for farmers and forest owners	50.0	500.0
Modernization of agricultural holdings	460.8	4,608.0
Increasing the added value to basic agricultural production	150.0	1500.0
Improvement of infrastructure related to the development of agriculture	76.5	765.0
Participation of farmers in food quality schemes	20.7	207.0
Information and publicity	3.6	36.0
Producer groups	16.8	168.0
Less-favored areas (LFA)	2,448.8	2,448.8
Agri-environmental program	1,240.0	3,860.0
Afforestation of agricultural and non-agricultural land	237.0	660.0
Restoring forestry production potential damaged by natural disasters	14.0	140.0
Diversification into non-agricultural activities	50.7	506.9
Establishment and development of micro-enterprises	210.0	2,100.0
Basic services for the economy and rural population	430.0	4,300.0
Village renewal and development	123.0	1,230.0
Total	7,468.7	28,397.1

Source: own elaboration based on Fragnelli and Kiryluk-Dryjska, 2017.

different RDP measures are calculated based on the farmers' assessment of the importance of political programs.

The farmers are the primary beneficiaries of rural development measures and are directly impacted by the budget allocation. The farmer population was assessed using a questionnaire-based survey with 2,900 representative PRDP beneficiaries sampled for the purpose of the Program's mid-term evaluation[5]. In the survey, the responders were asked to assess the contribution of different measures to rural and agricultural development on a scale from one (low impact) to nine (high impact).

The upper bounds for each measure (the maximum amount of money which can be allocated to a policy program) reflect all the options of fund absorption, including liabilities under previous programs. This paper used the same method for calculating the upper and lower bound as that discussed by Fragnelli and Kiryluk-Dryjska (2017). The upper bound is calculated under the assumption that all eligible beneficiaries would apply for a specific measure, taking two variables into account: (1) the unit support for each measure, and (2) the size of the target group of beneficiaries who meet the program's eligibility criteria. To ensure that every measure receives financial support, lower bounds are defined either as the amount of liabilities under previous rural development programs, or as 10% of the relevant measure's upper bound, whichever is higher. The upper and lower bounds are provided in Table 1. The linkage between the farmers' assessments and upper and lower bounds is based on the method proposed by Kiryluk-Dryjska (2014).

Considering that beneficiaries rate a given measure on a scale, the pay-off scheme must associate each rating with a specific payment amount. For this purpose, the beneficiaries' ratings were grouped into intervals. The intervals

[5] A questionnaire-based survey was conducted in 2010. The survey only covered farmers who had applied for the PRDP measures. A stratified random sampling scheme was used to guarantee adequate representation of all geographic regions and to account for differences in the population density of Polish rural areas. A total of 2,400 individual farmer questionnaires were completed and included in the analysis.

Table 2. Pay-off table linking the farmers' rating intervals with a fixed share of upper bounds for all measures

Decile (*i*)	Farmers' rating intervals defined by deciles		Fixed share of upper bound (*i*/10)
1	3.852	4.103	0.1
2	4.104	4.242	0.2
3	4.243	4.427	0.3
4	4.428	4.461	0.4
5	4.462	4.698	0.5
6	4.696	4.815	0.6
7	4.816	5.059	0.7
8	5.060	5.910	0.8
9	5.911	6.222	0.9
10	6.223	7.567	1

Source: own elaboration based on Kiryluk-Dryjska, 2014.

are then linked with a fixed share of the upper bound for a measure. Given that K is the total number of intervals and the beneficiaries' mean rating for a given measure falls within an interval i, $i \in \langle 1,K \rangle$, the fixed share of the upper bound for this measure is i/K. In order to calculate the actual amount of money to be allocated to this measure, the above share is multiplied by the measure's upper bound. For example, for the measure with the highest ratings, $i = K$; therefore, the measure is financed at its upper bound. Conversely, a measure with the lowest ratings is financed at a fraction of $1/K$ of its upper bound.

The pay-offs linking farmers' rating intervals with a fixed share of the upper bounds for all measures are presented in Table 2.

It is assumed that a fixed share of the upper bound for a measure (Table 2) multiplied by its upper bounds (Table 1) constitutes a *claim* (Table 3). For example, *Training for persons employed in agriculture and forestry*, with a rating of 4.674, falls in the fifth interval (4.462–4.698); 50% of the corresponding upper bound is assigned to it (a claim of EUR 24 million). Similarly,

Table 3. Farmers' rating, % of the upper bound, claims reported under different measures

	Farmers' rating	Share of the upper bound (%)	Claims (EUR million)
Training for persons employed in agriculture and forestry	4.674	50	24
Setting up of young farmers	6.082	90	468
Early retirement	4.425	30	1 440
Advisory services for farmers and forest owners	4.461	40	200
Modernization of agricultural holdings	7.567	100	4 608
Increasing the added value to basic agricultural production	4.091	10	150
Improvement of infrastructure related to the development of agriculture	4.911	70	535.5
Participation of farmers in food quality schemes	4.109	20	41.4
Information and publicity	3.852	10	3.6
Producer groups	4.461	40	67.2
Less-favored areas (LFA)	6.07	90	2 203.92
Agri-environmental program	6.55	100	3 860
Afforestation of agricultural and non-agricultural land	4.717	60	396
Restoring forestry production potential damaged by natural disasters	4.25	30	42
Diversification into non-agricultural activities	5.672	80	405.52
Establishment and development of micro-enterprises	5.076	80	1 680
Basic services for the economy and rural population	4.238	20	860
Village renewal and development	4.792	60	738

Source: own calculations.

Table 4. Allocation of the PRDP budget based on the adjusted uniform gains algorithm

Measure	Uniform gains procedure allocation (EUR million)	Share of the total budget (%)
Training for persons employed in agriculture and forestry	24.0	0.2
Setting up of young farmers	468.0	3.0
Early retirement	1 880.0	12.0
Advisory services for farmers and forest owners	200.0	1.3
Modernization of agricultural holdings	2 891.9	18.4
Increasing the added value to basic agricultural production	150.0	1.0
Improvement of infrastructure related to the development of agriculture	535.5	3.4
Participation of farmers in food quality schemes	41.4	0.3
Information and publicity	3.6	0.0
Producer groups	67.2	0.4
Less-favored areas (LFA)	2 448.8	15.6
Agri-environmental program	2 891.9	18.4
Afforestation of agricultural and non-agricultural land	396.0	2.5
Restoring forestry production potential damaged by natural disasters	42.0	0.3
Diversification into non-agricultural activities	405.5	2.6
Establishment and development of micro-enterprises	1 680.0	10.7
Basic services for the economy and rural population	860.0	5.5
Village renewal and development	738.0	4.7
Total and average	15 723.8	100.0

Source: own calculations.

100% of the corresponding upper bound is assigned to the *Modernization of agricultural holdings* with an average rating of 7.567 (a claim of EUR 4,608 million). In the case of *Early retirement* and *LFA*, the lower bounds (Table 1) were higher than the claims resulting from the pay-off table (Table 3). Thus, lower bounds are considered as claims in the allocation procedure.

Because the claims amount to a total of EUR 18,384.02 million – which is more than the total budget of EUR 15,723.8 million – it is reasonable to use the uniform gains procedure for a deficit.

RESULTS

According to the Moulin's (2003) algorithm, in order to obtain a common share λ, the total budget t (EUR 15,723.8 million) is divided into n (18) political measures of the 2007–2013 PRDP. Then, all the claims below that value – as reported under different measures – may be fully satisfied. The claims reported under 13 measures are fulfilled in the first step of the procedure. Afterwards, the remaining budget of EUR 11,792.6 million is divided by the number of remaining claims. Again, the claims lower than the common share are satisfied (*Establishment and development of micro-enterprises* and *Early retirement*). Next, in accordance with the procedure, *LFA* funds are disbursed, and the remaining budget of EUR 5,783.8 million is divided evenly between the two measures with the highest claims[6]. Table 4 shows the final allocation resulting from the algorithm, and the distribution of the total budget.

Out of the total budget of EUR 15,723.8 million, 18.4% would be allocated evenly to *Modernization of agricultural holdings* and *Agri-environmental program.*

[6] Another approach to the fair-division procedure could be that the bids above the egalitarian share simply receive equal parts of the remaining budget (constrained by the upper and lower bounds) or the amount claimed by the beneficiaries, whichever is lower. However, this one-step procedure fails to differentiate the pay-offs for measures with bids above the egalitarian level.

These are the measures with the highest claims reported by beneficiaries; 15.6% and 12% would eventually go to *LFA* and *Early retirement*, respectively. However, as regards these measures, the algorithm is strongly restricted by their lower bounds and does not reflect the farmers' ratings. Around 11% is allocated to *Establishment and development of micro-enterprises*. The remaining measures obtain less than 10% of the budget. In turn, some measures are provided with a small portion of the total budget which, however, represents a high percentage of their upper bound. For example, while *Setting up of young farmers* receives only 3% of the total budget, it amounts to 90% of its upper bound which guarantees the support for 90% of potential beneficiaries of this measure (Table 3). This is because the measure was highly rated by the farmers.

Figure 1 presents the difference between the uniform gains procedure allocation and the actual budget allocated by the Ministry of Agriculture and Rural Development. The comparison between the proposed and the ministerial budget demonstrates that the outcome of the procedure remains within a reasonable interval. However, the uniform gains procedure assigns more funds to measures highly rated by farmers, such as *Setting up of young farmers*, *Modernization of agricultural holdings*, *Agri-environmental program, Diversification into non-agricultural activities, Establishment and development of micro-enterprises, Village renewal and development*. As a result, all other measures are provided with less funds. Assigning more resources to measures highly rated by beneficiaries should improve program acceptance and encourage farmers to apply for the program's measures.

DISCUSSION

The application of fair-division algorithms to real-life political cases remains troublesome for several reasons. First, in order to apply the algorithms, the stakeholders need to reveal their preferences. In the case of political programs, collecting the stakeholders' feedback might be a costly and time-consuming process which therefore is difficult to put in practice. Second, each fair-division algorithm needs to be adjusted to a specific allocation problem. This requires some additional procedures and rules which need to liaise with the original algorithm.

The proposed approach is alternative to an earlier one proposed by Kiryluk-Dryjska (2014) and Fragnelli and Kiryluk-Dryjska (2017). While all of them emphasize

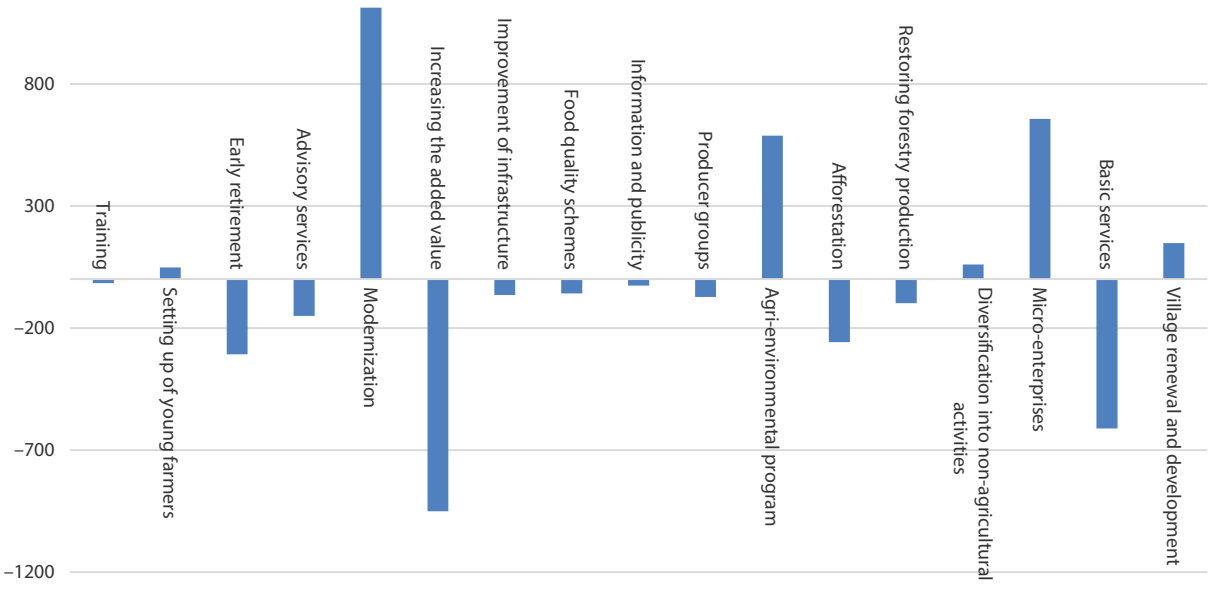

Fig. 1. Difference between the uniform gains procedure allocation and the actual budget allocated by the Ministry of Agriculture and Rural Development (EUR million)
Source: own calculations.

the criterion of fairness in the distribution of rural funds, they are underpinned by different algorithms. In the Brams and Taylor's algorithm used by Kiryluk-Dryjska (2014), the basis for budget allocation is the average difference in policy programs' ratings between different groups of key stakeholders with respect to predefined upper and lower bounds of financing for each program. The algorithm yields the egalitarian outcome as a result of unique bids left after the iterated elimination of weakly dominated strategies used by different groups of stakeholders. In this paper, the claims are based directly on ratings of just one group of beneficiaries. Thus, although there is a unique pay-off table linking the farmers' rating intervals to a fixed share of the upper bounds for all measures in both approaches, the allocation procedures differ significantly; both of them could be potentially used to allocate the policy budget. From a practical standpoint, the approach adopted in this paper is more feasible as it requires assessing only one group of stakeholders. Thus, it takes less effort and money to collect the data[7].

This method also differs from the approach presented by Fragnelli and Kiryluk-Dryjska (2017). The fair measure proposed by the authors is based on calculating the relevance of factors affecting a repetitive event, taking into account their occurrence frequency. The results depend only on the index computed based on expert opinions and is not impacted at all by the lower and upper bounds. The bounds are considered as constraints but are not included in the computation of amounts assigned to each program. Conversely, in the approach proposed in this paper, upper and lower bounds have a significant impact on claims and, consequently, on the allocation of the total budget.

CONCLUSIONS

This paper showed how the uniform gains procedure could be adjusted to, and used in, a real-life allocation problem: the allocation of rural development funds in Poland. To discover the stakeholders' preferences, a questionnaire was used where the farmers could rate the programs' importance. The algorithm was adjusted to the allocation of funds under the 2007–2013 PRDP by setting upper and lower bounds for the measures concerned, and using a pay-off table which respects the farmers' ratings. The results showed that the procedure allocates the total budget among the program measures in a reasonable way. The outcomes are similar to the actual allocation of funds. Moreover, it reflects the importance of measures, as rated by the beneficiaries, and the options for fund absorption. As a formal and structured method, it also objectifies the decision-making process, and should therefore improve the programs' acceptance among stakeholders. Naturally, a greater acceptance of a program motivates the beneficiaries to implement the relevant measures and attain the desired outcomes.

This paper presents the feasibility of a solution which is an alternative to algorithms presented earlier in the literature and emphasizes the importance of fairness as a key criterion of public choice. Though based on the 2007–2013 Polish Rural Development Program, the approach presented in this paper is a universal tool which could be used in any structural policy program.

[7] On the other hand, considering only one group of beneficiaries can be regarded as a limitation of the approach. Thus, pros and cons of these methods need to be carefully analyzed before potential use.

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ZASTOSOWANIE ALGORYTMU SPRAWIEDLIWEGO PODZIAŁU DO ALOKACJI FUNDUSZY ROZWOJU OBSZARÓW WIEJSKICH UE W POLSCE

Abstrakt. Ze względu na zróżnicowanie wprowadzanych działań, dużą liczbę potencjalnych beneficjentów oraz brak jednoznacznych mierników efektów wprowadzanych programów alokacja budżetu rozwoju obszarów wiejskich jest niezwykle trudnym zadaniem. Celem artykułu jest zbadanie możliwości zastosowania algorytmu sprawiedliwego podziału zaproponowanego przez Moulina (2003) do alokacji budżetu rozwoju obszarów wiejskich na przykładzie Programu Rozwoju Obszarów Wiejskich 2007–2013. Wyniki alokacji, uzyskanej przy wykorzystaniu zaprezentowanej procedury, uwzględniają oceny skuteczności działań nadane przez beneficjentów oraz możliwości absorpcji środków. Ponadto zastosowanie algorytmu obiektywizuje proces decyzyjny, co powinno pozytywnie wpłynąć na akceptację programu wśród beneficjentów.

Słowa kluczowe: podział sprawiedliwy, rozwój obszarów wiejskich, rozdysponowanie budżetu