
A Hybrid Simulation Approach to Modelling the Impact of Public Interventions on Poverty*

Submitted 21/09/19, 1st revision 10/10/19, 2nd revision 28/10/19, accepted 04/11/19

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Abstract:

Purpose: The aim of the article is to present the concept of a hybrid simulation model to study the impact of public intervention on the level of poverty at the local, regional and national levels.

Design/Methodology/Approach: The proposed model is the hybrid of two computer simulation methods Agent-Based Simulation (ABS) and System Dynamics (SD).

Findings: Counteracting the phenomenon of poverty is one of the tasks of public administration units. Various tools and instruments can be used to fight poverty, as a part of numerous programs financed from public funds, but their implementation should be preceded by a thorough analysis of the effects arising after their application. This is not easy, because the phenomenon of poverty is very complex, it results from the arrangement of many interrelated elements, and the outcomes of actions are visible only after a longer period of time. This system is characterized by the heterogeneity of elements. Some of them are on a macro scale (e.g. GDP level, labour market), while others refer to the micro scale (e.g. households and their members). Building a model of households requires the use of a method that allows to reflect the behaviour and decision-making rules of individuals and the interaction between them in a disaggregated form. Agent-Based Simulation (ABS) is such a method. On the other hand, modelling elements occurring in the macro scale, where we usually deal with aggregate quantities, is best matched by System Dynamics (SD) simulation method, which allows for reflecting dynamic behaviour through feedback loops.

Practical Implications: The proposed concept can be used both by public administration units at various levels as well as by scientists - to conduct socio-economic research.

Originality/Value: The applied simulation approach allows to capture the interrelations between the modelled effects in a dynamic manner for a long-time horizon, which is extremely important in the case of public management activities.

Keywords: Hybrid simulation, poverty, public management, public intervention, ex-ante evaluation.

JEL codes: C63, I32, H83.

Paper type: Research article.

*An earlier version of this article has been presented in ICABE 2019 www.icabe.gr

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Acknowledgements:

The project is financed within the framework of the program of the Minister of Science and Higher Education under the name “Regional Excellence Initiative” in the years 2019–2022, project number 001/RID/2018/19, the amount of financing PLN 10,684,000.00.

1. Introduction

Poverty, understood as the deprivation of material means to satisfy the basic life needs of an individual or a family (Bukowski and Magda 2013), is still common. This is evidenced by the data announced by the European Statistical Office, according to which in 2016 the number of people at risk of poverty in the European Union (EU) reached 17.3%, i.e. over 85 million (Eurostat, 2018). Therefore, it is not surprising that the international community committed to reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions by 2030 (United Nations, 2015). According to international development agencies, implementation of good governance in public administration units is crucial to achieving this (United Nations, 1998) which is documented by many studies focused on the association between good governance and poverty. The review of them can be found in Jindra and Vaz (2019).

The implementation of poverty reduction programmes developed by public administration units (represented by various actors, bodies and institutions, both at central and local level) requires substantial public resources - financial, human and physical. It is therefore obvious that, according to the principles of good governance, these programs should be preceded by a thorough analysis of the expected effects (Gisselquist, 2012). This is not easy, because poverty is a very complex phenomenon. Both its causes and effects are interrelated and form a network of interdependencies, often non-linear, of a feedback nature. In addition, the effects of the steps taken are only visible after in a relatively long time horizon (Diris, Vandenbroucke and Verbist, 2014). The analysis of such a complex system requires an approach that will deal with the complexity of this phenomenon in a dynamic perspective. In the opinion of the authors, this is a computer simulation. However, the system under study is characterized by the heterogeneity of elements. Some of them are on a macro scale (e.g. GDP level, labour market), while others refer to the micro scale (e.g. households and their members), which can pose considerable challenges for a single-methodology simulation approach. In such a case an alternative approach, using a hybrid simulation, defined as a combination of two or more computer simulation methods can provide a simpler and more natural solution (Brailsford *et al.*, 2019).

Building a simulation model of households requires the use of a method that allows to reflect the behaviour and decision-making rules of individuals and the interaction between them in a disaggregated form. Agent-Based Simulation (ABS) is such a method. On the other hand, modelling elements occurring in the macro scale, where we usually deal with aggregate quantities, is best matched by System Dynamics

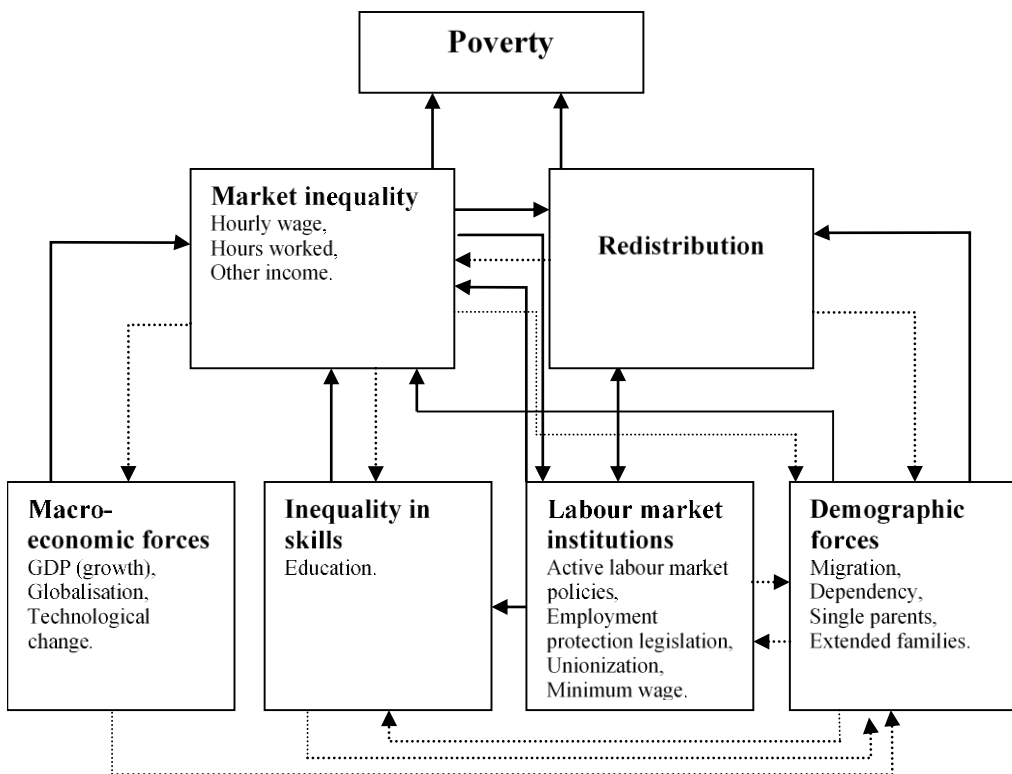
(SD) simulation method, which allows for reflecting dynamic behaviour through feedback loops.

The aim of the article is to present the concept of a hybrid SD- ABS model to study the impact of public intervention on the level of poverty at the local, regional and national levels. Moreover the article briefly describes both methods and discusses the issue of combining them in a single model.

2. Literature Review

Activities aimed at poverty reduction focus primarily on the use of social policy tools related to various forms of government redistribution (Diris, Vandebroucke and Verbist, 2014) and are usually public interventions, i.e. activities involving public resources (Rosiek, 2012). However, public intervention does not always lead to the expected improvements. Therefore, prior to the implementation of a specific intervention, it is advisable to carry out an in-depth analysis of the expected effects of its implementation. This is not easy, as poverty is a consequence of many factors, with mutual (mainly non-linear) interdependencies between them, which are often of a feedback nature (Figure 1).

Figure 1. Poverty determinants



Source: (Diris Vandebroucke and Verbist, 2014, p. 43).

In practice, the effects of public intervention are most often assessed *ex-post* by evaluation carried out by means of various methods (Łatuszyńska and Fate, 2017). However, the essence of the evaluation process should not only be the observation of past events, but first of all the knowledge of the effects of planned activities. In order to estimate them, various models are usually used (Piech, 2008).

Table 1 lists the models most frequently mentioned in the literature. Those models were not developed specifically to study the impact of public actions on poverty, but they can nevertheless, to a smaller or larger extent, be used to determine certain indicators in this respect. The table indicates: type of model (static/dynamic), selected indicators calculated by the model, level to which the model refers (local, regional, national, international), availability of model documentation, IT support (software tools), and usefulness to study the impact of public intervention on poverty prevention.

Table 1. *Models used for public interventions effects assessment*

Model name	Model type	Selected indicators	Documentation	Level	IT support	Poverty analysis
EDUMOD (Ramsza, Kowal and Lis, 2015)	Dynamic	employment rate of the population aged 15-64 (%); education of people aged 15 and over (%)	Yes	National, Regional	C, C#	Indirect
EU-ImpactMod (Bukowski and Wierus, 2011)	Dynamic	total employment rate (percentage points); at-risk-of-poverty rate relative to total social transfers (percentage points).	Limited	National	-	Direct
EUROMOD (Sutherland and Figari, 2013)	Static	poverty risk rate in %, risk of poverty among children in %	Yes	International (EU countries)	MS Excel	Direct
HERMIN (Bradley, Zaleski and Tomaszewski, 2005)	Static and dynamic	Number of new jobs, change in GDP.	Yes	National, Regional	WINS OLVE	Indirect

Model name	Model type	Selected indicators	Documentation	Level	IT support	Poverty analysis
INES (Fontaine and Sicsic, 2016)	Static	poverty rate, inequality rates	Limited	National, Regional	-	Direct
MaMoR2 (Kaczor, 2006)	Static	employment rate of people aged 15-64 (%), unemployment rate of people aged 15-64 (%).	Limited	National, Regional	-	Indirect
Tax-and benefits model (Konopczak and Skibicki, 2012)	Static	average per capita income (in PLN), change in per capita income relative to baseline scenario (in PLN and in %), relief cost (in PLN).	Limited	National	MS Excel	Direct
Model of Polish economy (Karpińska-Mizielińska <i>et al.</i> , 2006)	Static	GDP growth rate in %, employment of people aged 15-64 in %.	Limited	National	-	Indirect
MYRIAD E (Blanchet, 2014)	Static and dynamic	unemployment rate in%, demographic indicators, incl. migration rate (in people).	Limited	National	Application in C++	Indirect
NECMOD (Przybylska-Kapuścińska and Szyszko, 2009)	Dynamic	GDP (percentage points), exchange rate (%), CPI inflation (percentage points)	Yes	National	-	Indirect
SIMPL (Domitrz <i>et al.</i> , 2013)	Static	poverty rate	Limited	National	MS Excel, Access and Visual Studio	Direct

Model name	Model type	Selected indicators	Documentation	Level	IT support	Poverty analysis
SWITCH (Callan <i>et al.</i> , 2012)	Static	poverty and social exclusion indicators	Limited	National	-	Direct
SYSIFF (Ca-nova, Piccoli and Spadaro, 2015)	Static	poverty indicators	Limited	National, Regional, Local	MS Excel	Direct
TÁRSZIM (Benedek, Scharle and Szabó, 2007)	Static	average tax per household, average household tax rate by number of children	Limited	National	MS Access	Indirect
TAXBEN (Brewer <i>et al.</i> , 2009)	Static	child poverty rate (%), material deprivation rate (%).	Limited	National, Regional	Application in Delphi	Direct

Source: (Łatuszyńska and Fate, 2017).

When discussing the contents of Table 1, it should be emphasized that it is very difficult to find a complete documentation for any of the presented models. The available literature lacks detailed descriptions of their assumptions, structure and functioning, whereas available data tends to be general and selective, which results in most of these models being "black boxes". It is therefore difficult to fully evaluate their suitability for analysing the impact of public interventions on poverty. Nevertheless, the analysis of the available data allows to put forward certain basic conclusions.

Most of the analysed models are static and so they can provide only point-based forecasts for a definite moment in time (year), which does not allow taking into account the secondary effects of public actions resulting from the internal structure of the studied effects system, especially when the analysis concerns a long-term time horizon. With dynamic models, only one, i.e. EUImpactMod, allows direct determination of indicators related to poverty, but it is possible to apply it at national level only, while many public interventions for reducing poverty are regional, or even local, and it would be advisable to rely on tools developed for carrying out analyses at these levels.

Some of the presented models use IT tools, mainly MS Excel spreadsheet. The advantage of this solution is fairly simple functionality although cause-and-effect relationships defined in analytical models created using spreadsheet are unidirectional, which does not fully reflect the mechanisms of public intervention

effects that result from multilateral feedbacks, time delays and non-linearity of relationships between the basic elements of a complex socio-economic reality. In summary, it can be stated that there is an evident need to develop a model that would be dedicated directly to the impact of public activities on poverty and would allow *ex-ante* evaluation not only at international or national level, but especially at regional and/or local level. It is also important for that model not to be one-off so that it can be used to anticipate the effects of various public interventions for poverty reduction. A hybrid model built using two methods of computer simulation, Agent-Based Simulation and System Dynamics, can be such a tool.

3. Methodology

DS and ABS approaches are iconic in the way that they are often presented as exclusive alternatives to analyse complex systems (Swinerd and McNaught, 2012; Martin and Schlüter, 2015). Many scholars argue that the choice of an appropriate approach to adopt in a particular case should depend on the nature of the system at hand and the purpose of the model (Stemate, Pasca and Taylor, 2007; Swinerd and McNaught, 2012; Martin and Schlüter, 2015). Swinerd and McNaught (2012) suggest that many systems can be modelled in equivalent ways by both paradigms. However, they conclude that sometimes one paradigm presents a more natural choice than the other (Wallentin and Neuwirth, 2017).

System Dynamics approach was founded more than 50 years ago by Forrester (1958) around two notions from systems theory: (1) aggregated-level variables effect each other through feedback loops, (2) system's structure drives system's behaviour (Nava Guerrero, Schwarz and Slinger, 2016).

The building blocks in specifying an SD model are stocks, flows and auxiliary variables (Forrester, 1958; Sterman, 2000). Stocks represent the accumulation of material and information, caused by the action of inflows and outflows. While stocks are mathematically described by integral equations, flows are described by differential equations (Macal, 2010). These sets of equations are solved through numerical integration at discrete time steps. The solution describes the system aggregated state changing continuously over time and depending on the previous state of the system (Forrester, 1958; Sterman, 2000).

In contrast to SD, ABS models the structure of a system as the result of decentralized decisions of individual entities or agents over time (Macal and North, 2006; Macal, 2010). Therefore, instead of assuming a given system structure, agents' decisions shape and change the state and structure of the system. In turn, agents react to the dynamic changes in the system, which can potentially alter their decision rules (Nava Guerrero, Schwarz and Slinger, 2016).

Various disciplines worked out their own ways of understanding the term “agent”. It is commonly accepted that agents are placed in certain environment and they are able to take autonomous actions (Macal and North, 2006).

The main building blocks of ABS models are: agents, their decision rules and actions, and the environment in which they interact (Epstein, 2006). ABS approach generally focuses on micro-level interactions that may explain emergent patterns such as transient dynamics on a system level (Martin and Schlüter, 2015). Ding *et al.* (2018) indicate three reasons justifying the combination of both approaches:

- SD models do not take into account different levels of aggregation, while ABS gives the possibility of mapping a fine level of detail. Thus, SD can be used to reflect the highest level of abstraction, while ABS can be used to reflect the lower levels of abstraction, depending on the nature and scale of the elements.
- SD does not allow the inclusion of heterogeneous elements. Each stock is composed of homogeneous elements. The diversity of elements must therefore be modelled by adding new stocks. However, the heterogeneous elements (agents) can be easily established using ABS.
- SD is equation-based, and needs quantified relationships between variables; thus, it is not suitable for complex systems with unknown structures. However, ABS can reasonably represent complex systems based on a limited number of relatively simple rules to reveal emergent behaviour.

Some pioneering work on the linking System Dynamics and Agent-Based Simulation was conducted among others by Scholl (2001), Schieritz (2002) and Größler, Stotz and Schieritz (2003). Till date, many studies have been made on combining SD and ABS and the use of this hybrid to study problems in various disciplines, including studies on how to integrate the two approaches. The structured review of these studies can be found in (Łatuszyńska, 2019) performed in March 2019 in Scopus and Science Direct databases. None of the studies reviewed presented applications of the SD-ABS hybrid for research on poverty.

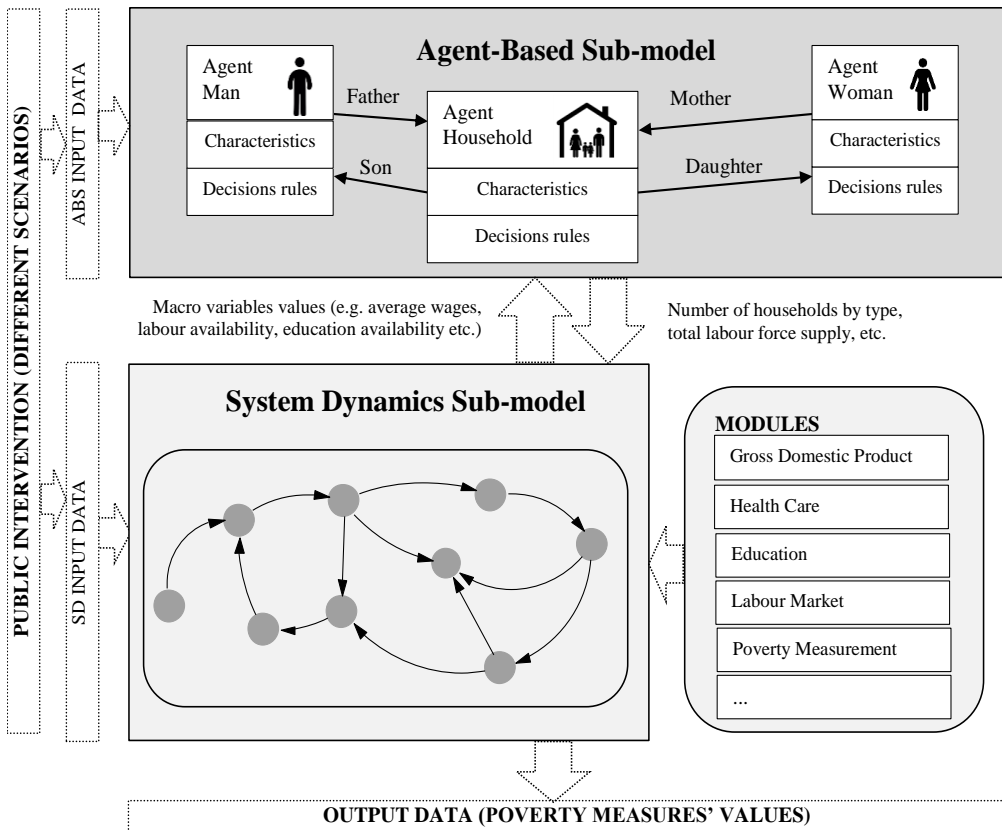
4. Research Results and Discussion

The research carried out allowed the development of a hybrid concept to study the impact of public interventions on poverty levels. The general structure of the model is presented schematically in Figure 2. The model consists of two sub-models: the Agent-Based and the System-Dynamics, between which there are relations of a nature of feedback.

The Agent-Based Sub-model (ABS) consists of three agent types: (1) man (M), (2) woman (W) and (3) household (H), where the agent 'household' is created by a linkage between an agent of the 'male' type (father) and a 'woman' agent (mother), simultaneously being a source of M (son) and W (daughter) agents. Each type of an agent is assigned certain features and decision-making rules.

Both types of agents M and W are described by certain characteristics. These include: age, probability of death depending on age; acceptable age difference from partner to partner (different for women and men); education (primary, secondary, higher); age of first employment (depending on education); retirement age (e.g. 65 for men and 60 for women); socio-economic group membership (e.g. employee, farmer, pensioner, living on unearned sources); earnings group (determined on the basis of obtained remunerations, resulting from the multiplicity of the national average); current level of income (by quintile, decile or other groups); source of income (e.g. from employment, self-employment outside agriculture, retirement or disability pension, from non-profit sources); degree of disability (zero value means no disability). Additionally, a ‘woman’ agent is assigned a feature specifying the number of children (expected and current).

Figure 2. General structure of SD-ABS hybrid model to study the impact of public intervention on the level of poverty



Source: Authors' elaboration.

Interactions between agents and their way of functioning in the environment result from the rules of decision making assigned to them, such as pairing, employment,

improving professional qualifications, allocation of income when finding employment. A 'woman' agent also has an assigned a rule for making decisions about giving birth to a child.

The third type of agent in the Agent-Based Sub-model is the household (H). The most important features of this agent include: focus on the mother (0 - means her absence from the household); focus on the father; number of children, class of place of residence (e.g. village, city). In addition, each H agent is assigned the rules that are relevant for the measurement of the poverty level, such as the rule of determining the biological type (e.g. a one-person household, a couple without children, a couple with two children, a mother with dependent children, etc.); calculating the number of household members, total household income and equivalent income as well as determining the minimum income per capita eligible for social assistance benefits. Additionally, the rules of indicating the head of family and marriage breakdown are defined as well as the household's entitlement to social welfare benefits.

In order to determine the value of characteristics of all types of agents and to define detailed rules for the functioning of agents in the environment, input data is needed, which in some cases are provided by law (e.g. retirement age). They can also be calculated on the basis of generally available statistical data (e.g. probability of child birth depending on mother's age or probability of childlessness) or developed on the basis of survey results. They may also come from experts (e.g. expressing their opinions in reports, publications, etc., or through direct individual or group interviews or expert panels). An important group of input data comes from the SD sub-model. These are macro variables values (e.g. average wages, labour availability, education availability, etc.), on the basis of which agents take appropriate action in accordance with the rules assigned to them.

The Agent-Based Sub-model is designed to disaggregate the demography and population of the area for which the poverty level is to be measured. It may refer to a specific administrative unit, for example: a comune, a county, a voivodship, or the whole country - whatever the need may be. The populations of 'woman', 'man' and 'household' agents correspond to the numbers actually recorded in the area.

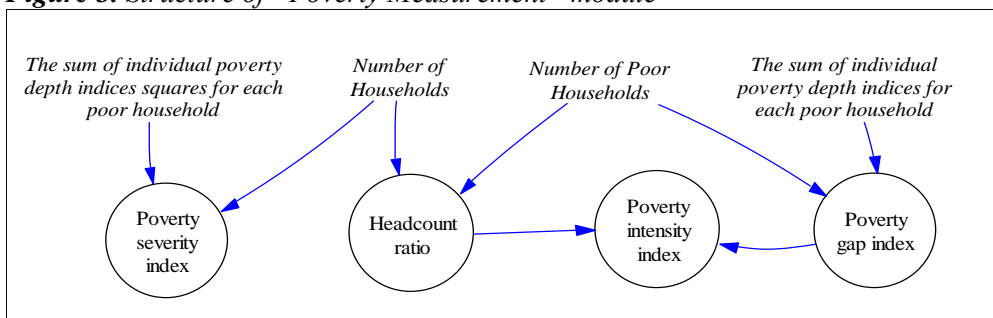
From the ABS sub-model, data mainly concerning the number of households determined for the analysed area are transferred to the SD sub-model, i.e. the total number of households, as well as the number of households with selected characteristics, including those with income equivalent lower than the poverty line (e.g. the number of four-person households living in rural areas, where the head of the family depends on hiring). It should be stressed that the number of possible combinations of the tested household characteristics is vast. Assuming that only characteristics such as socio-economic group, type of household, level of education of the head of household and class of place of residence will be taken into account in a given survey, and that each characteristic can have only three values (e.g. an elementary, secondary and higher level of education), 81 different groups of

households are obtained. Thanks to the data calculated in the ABS sub-model, it is possible to determine basic indicators of poverty in the SD sub-model, for example: headcount ratio, poverty gap index, income gap index, etc. (Latuszyńska and Fate, 2018; Piwowarski *et al.*, 2018), broken down by the type of household. In addition to calculating the values of the individual poverty indicators, the SD sub-model is designed to map out the macroeconomic factors affecting the level of poverty and the relations between them. In accordance with the nature of the System Dynamics method, these factors are modelled in an aggregated way.

It should be stressed that the phenomenon of poverty is very complex and depends on many factors, which are intertwined and complicated (mainly non-linear) and often of a feedback character. They have been widely discussed by numerous authors such as Foster *et al.* (2013), Diris, Vandenbroucke and Verbist (2014) and Cowell (2016). Due to the large number of these factors, the authors propose to use a modular approach when creating the SD sub-model. They assume that system modelling is based on the creation of a ‘model of models’, i.e. a heterogeneous structure consisting of many structural blocks, called modules. Modules are defined as small blocks in the system-dynamic convention. They include elements of system-dynamic notation (levels, streams, auxiliary variables, parameters) and instructions for formal simulation language (Vensim, Powersim, IThink, etc.). Modules serve as building material in the construction of the target model, but, as mentioned above, they can be models themselves (Latuszyńska, 2004).

In the case of the presented concept, each module refers to a specific macroeconomic factor which, according to the literature, has an impact on the level of poverty, for example: Gross Domestic Product, health care, education, labour market etc. The set of modules can not only be freely extended by defining new ones on the basis of observation and following the theory concerning the examined system, but also by adapting ready-made system-dynamic models relating to modelled macroeconomic factors. The structure of the sample module, the ‘Poverty Measurement’, is shown in Figure 3 in the notation of the Vensim DSS simulation package.

Figure 3. Structure of “Poverty Measurement” module



Source: Authors' elaboration.

The index values set in this module permit the assessment of the impact of planned public interventions on the level of poverty. These indexes are modelled on the basis of the formulas presented in Table 2. Of course, they are only selected, classic indexes, as there are many other one-dimensional and multidimensional measures that can be used to assess the poverty level (Piwowarski *et al.*, 2018), and they can also be included in the set of modules.

Table 2. Selected classical aggregate poverty indexes

Index	Formula	Explanation	Aspects of evaluation
Headcount ratio H	$H = \frac{n_u}{n}$	n number of sample households, n_u number of poor sample households in surveyed population.	poverty incidence
Poverty gap index I^u	$I^u = \frac{1}{n_u} \sum_{i=1}^{n_u} \left(\frac{y^* - y_i^e}{y^*} \right)$	y_i^e equivalent income of i th household, y^* numerical value of poverty line.	poverty depth
Poverty intensity index I^o	$I^o = H.I^u$	H Headcount ratio I^u Poverty gap index	poverty intensity
Poverty severity index DU	$DU = \frac{1}{n} \sum_{i=1}^{n_u} \left(\frac{y^* - y_i^e}{y^*} \right)^2$	n number of sample households, y_i^e equivalent income of i th household, y^* numerical value of poverty line.	poverty severity

Source: Authors' elaboration based on Panek, 2011, 62-64.

Each of these indexes can be calculated for different groups of households (Household Category) and for a specific territorial unit (Region), which can be seen in the system of equations describing individual elements of the 'Poverty Measurement' module in the notation of the simulation language of the Vensim DSS package (Figure 4). But not only - any cross-sections resulting from a set of features and rules describing agents in the ABS sub-model are possible as well.

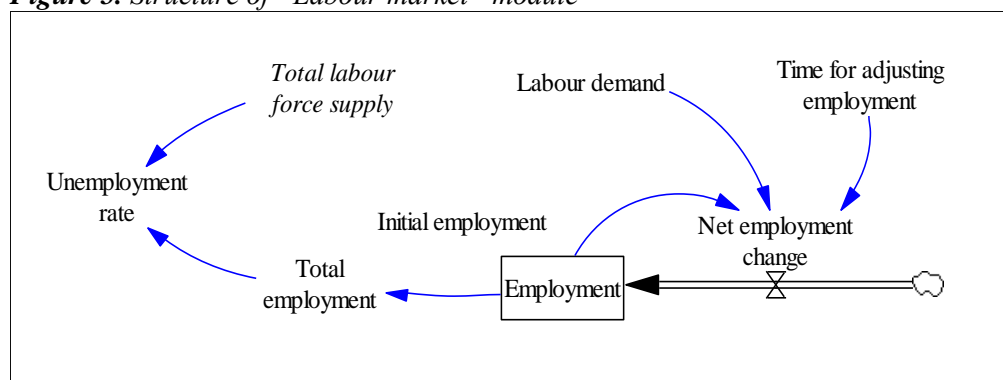
The other modules in the set are developed on a similar basis, but, as mentioned above, they may be adaptations of existing system-dynamic models described in the literature and relating to the modelled macroeconomic factor that affects poverty. An example of a module created as a result of adjusting the existing SD model to the needs of the proposed concept is the 'Labour market' module presented in Figure 5. It has been created on the basis of documentation for the iSDG model developed by Millennium Institute (2017).

Figure 4. The system of "Poverty Measurement" module equations in the Vensim DSS simulation language notation

Headcount ratio [Household Category, Region]	=	Number of Poor Households [Household Category, Region]/Number of Households [Household Category, Region]
Poverty gap index [Household Category, Region]	=	The sum of individual poverty depth indices for each poor household [Household Category, Region]/Number of Poor Households [Household Category, Region]
Poverty intensity index [Household Category, Region]	=	Headcount ratio [Household Category, Region]*Poverty gap index [Household Category, Region]
Poverty severity index [Household Category, Region]	=	The sum of individual poverty depth indices squares for each poor household [Household Category, Region]/Number of Households [Household Category, Region]
Number of Households [Household Category, Region]	=	calculated in ABS sub-model
Number of Poor Households [Household Category, Region]	=	calculated in ABS sub-model
The sum of individual poverty depth indices for each poor household [Household Category, Region]	=	calculated in ABS sub-model
The sum of individual poverty depth indices squares for each poor household [Household Category, Region]	=	calculated in ABS sub-model

Source: Authors' elaboration.

Figure 5. Structure of "Labour market" module



Source: Authors' elaboration based on Millenium Institute, 2017.

The only thing that this module reflects is the demand for labour force resources, as the supply data are derived from the ABS sub-model and broken down by socio-economic groups, education level, age groups and class of residence. The modules included in the set are used in the process of building the final SD sub-model.

For different variants of intervention, separate SD sub-models are constructed and calculations are performed in conjunction with the ABS sub-model, with data exchange between the modules taking place at each step of the simulated time. The results obtained by simulation for each individual option may be the basis for the choice of a specific intervention that will produce the desired effects in the form of poverty reduction. Taking the example of Poland as a starting point, these could

include such interventions as changes to the minimum wage and minimum pension, the introduction of a family allowance, state aid for raising children, the 500+ programme, etc., but also subsidies for creating new jobs or access to free training to improve professional qualifications

5. Conclusions, Proposals, Recommendations

The main objective of the proposed simulation model presented in the article is to provide information on the effects of public interventions being a part of anti-poverty activities implemented by public administration. The proposed concept of a hybrid model built with the use of two methods of computer simulation – System Dynamics and Agent-Based Simulation, makes it possible to avoid their individual constraints and allows for a more complete use of the potential of their complementary features, hence more accurate representations of complex dynamic systems can be provided. Models created on the basis of this concept can be used by:

- public administration units, and first of all government departments responsible for social security;
- local government units - while creating voivodship programmes and general strategic documents (e.g. strategy of solving social problems at the commune level);
- non-governmental organizations;
- research organizations - in order to conduct simulations as a part of their social and economic research.

It should be pointed out that the application of the proposed concept should be preceded by the resolution of problems related to the appropriate model software allowing for the synchronisation of the data flow between two sub-models and by the development of a simulation system acting as a generator of simulation models for individual public interventions. Currently, the assumptions for such a system are being developed.

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