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**CHOOSING AND EVALUATING TECHNOLOGY POLICY:
A MULTICRITERIA (NON NEOCLASSICAL) APPROACH**

Lucio Biggiero* & Domenico Laise**

*LUISS University
Viale Pola, 12
00198 - Rome - Italy
tel. +3906 86506780; fax. +3906 86506513; email biggier@luiss.it
<http://www.luiss.it/facolta/economia/biggiero>

**Università di Roma “La Sapienza”
Dipartimento di Informatica e Sistemistica
Via Buonarroti, 12
00185 Roma Italy
tel. +3906 48299240; fax. +3906 48299218
laise@dis.uniroma1.it

Introduction

In the era of knowledge-based and learning economy the issue of technology policy is getting a renewed attention (Bozeman, 2000; Cowling, 1999; Lundvall, 1999; OECD, 1998). The theorization of national (and regional, or even local) innovation systems (Archibugi, Howells & Michie, 1999; Baraczyk, Cook & Heidenreich, 1996; Cook, Uranga & Etxebarria, 1997; Edquist, 1997; Lundvall, 1992; Nelson, 1993; Teubal, 1998), jointly with the diffusion of the evolutionary perspective in economics and sociology (England, 1994; Hodgson & Screpanti, 1991; Metcalfe, 1998; Nelson, 1987, 1995; Rosenberg, 1994; Smelser & Swedeberg, 1994), is moving far from the simple and ethereal world of neoclassic economic theory (NET), and are showing the complexity of choosing and evaluating technology policy (Becher & Kuhlmann, 1995; Freeman, 1987; Georghiou & Roessner, 2000; Link, 1996, 1998; Meyer-Krahmer & Montigny, 1990; Papaconstantinou & Polt, 1997; Peterson & Sharp, 1998; Vonortas, 2000). However the debate seems still suffering on one side the seduction of NET and on the other side the lack of formal methods to decide and evaluate. Indeed the two things are strictly related, because often the resistance to abandon NET comes from the fact that it appears very theoretically robust, while the practices of decision making performed by institutions and even the methodologies proposed by the non-neoclassical theorists seem less rigorous and ongoing.

The seduction can be recognized in the frequent references made by evolutionary –or at least non neoclassical- theorists to typical neoclassical concepts, as optimization,

marginal costs, game approach, welfare function, knowledge function, etc. A large part of theorizing and making in technology policy is definitely moving from the neoclassical framework, abandoning the idea of equilibrium, production function, etc.. Some approaches are going even to be modeled, as the national innovation systems, the triple helix, and the genetic algorithm (Arthur, 1994; Kaufman, 1998). However, especially in the attempts to choose and evaluate technology policy the lack of a decision making procedure able to be practical and also non-neoclassical opens a big hole in the field, and allows for fostering the “neoclassical sirens”.

The gap can be filled in by some methods, called *outranking methods* (Roy, 1985; Roy & Bouyssou, 1993; Vincke, 1992), which are as robust as NET but are non-neoclassical. They can enrich the development of non-neoclassical approaches to technology policy in four main ways. First, they radicalize the move from NET, and at the same time reinforce its theoretical grounds, consisting in the behavioral-evolutionary economic theory (BET). Moreover they are definitely realistic, being easily applicable to choose and evaluate policy options, and any other kind of economic or social decisions. Finally, they allow to solve multicriteria problems, which instead cannot be faced by NET.

The Multicriteria Nature of Choosing and Evaluating Technology Policy

The choice and the evaluation of technology policy, as well as of any other kind of policy, are multicriteria. In other words, they imply the consideration of different economic, social and technical criteria at once. We could add that any human choice is multicriteria and that the unicriterion condition is an extreme case. We choose a car between competing products, based on the criterion of price, safety, size, comforts, speed, etc. The hardest question comes from the fact that, with special exceptions, criteria are conflicting ones, that is, they do not order our preferences in the same way. Moreover, we are speaking of genuinely independent criteria, that is, of criteria which are not reducible (transformable) each other through some parameter.

A brief glance at the literature on technology policy clearly show such a multicriteria nature. Depending on the geographical reference (national or regional or local), and depending on the theoretical and cultural backgrounds of policy makers (or of their consultants) many different criteria are set up. The same institution can have many different criteria, and usually changes them over time, because of changed priorities in the society and the economy. A criterion corresponds to an objective-function to maximize or satisfy. Well known examples are the GNP, the net employment, the average size distribution, the creation of new enterprises, the growth of productivity, the increase of firms' survival rates, etc.

In more specific technological terms, other criteria are the diffusion rate of ICT, the innovation rate, the R&D expenditure of business or non business organizations, the patent rate, etc. Looking at the last report on S&T (OECD, 2000), nearly all the indexes

could be used as criteria to choose or evaluate the technology policy. Hence, a problem of how face multicriteria decision making is raised.

The Neoclassical Approach

NET and game theory, which is its isomorphic non-parametric version, gives a clear and simple answer to that question: there is only one meaningful criterion, which is the maximization of the welfare function. The technology policy, to the extent it concerns a collective good, must choose the alternative which maximizes the welfare function. The problem is formalized in the following way, which is common to all the general neoclassical approach to welfare economics, collective goods and policy making:

$$\max(\min) \{G(h)/h \in H\}$$

where:

$G: \mathfrak{R}^{n+m} \rightarrow \mathfrak{R}^1$ is the objective-function (social utility, social welfare or social cost) of the policy maker;

$h = (z, w)$;

z is the vector of objectives of the policy;

w is the vector of instruments (interventions) of the policy;

$H = \{h/F(h) = 0\}$;

$F: \mathfrak{R}^n \rightarrow \mathfrak{R}^m$ is the function which expresses the working of economic system.

This is a unicriterial logic, based on the maxi- or minimization of some utility or welfare function. According to Arrow (1962), public policies for technological innovation are related to the “traditional” causes of public interventions in the economy: the presence of externalities and the characteristics of public goods. The latter are the non-rivalry in consumption and the non-separability of exploitation and benefits. Neoclassical theorists argue that the production and the exploitation of scientific knowledge embodied in an innovation show both peculiarities. This view leads Griliches (1990) to model the innovation process as a knowledge production function (Malerba & Torrisi, 2000). Through technological and industrial policy market failures are “repaired” by a “social planner”, who is perfectly rational and holds any useful or relevant information concerning the past, the present and the future of agents’ preferences, as well as about the states of nature.

The new industrial economics () and, according to Simon (1997), the new institutional economics too (), do not significantly change the framework. Emphasizing the disturbing role performed by the asymmetric distribution of information and of market power, they maintain the same neoclassical perspective: the determination of “virtual” points of equilibria by means of the maximization of utility functions and/or the minimization of production functions. Here “virtual” means that such points can be defined only at the price of a drastic oversimplification of the real world.

This logic can be criticized by a number of reasons, which run from more fundamental and theoretical ones, to less fundamental and more practical ones. Simon's (...) criticisms are of the fundamental type, based on the consequences of bounded rationality, ground the behavioral economic theory (BET), and shut the hard core of NET, because demonstrate the impossibility to be maximizers or minimizers. Nelson's & Winter's (1982) criticisms shape the evolutionary theory and its developments on national systems of innovation and on technology policy, and share the same framework of BET.

Many scholars in the field of public policy criticized the neoclassical perspective, and its derivatives. Especially evolutionary economists and the supporters of the national systems of innovation approach contrasted NET to technology policy, arguing both theoretical and empirical criticisms. They basically share Simon's critique, and its consequences of rejecting optima and equilibria. Moreover they underline, on the empirical side, the boundedness of the rationality of the social planner, and thus the unavoidable frequent failures of its interventions (). However these criticisms are often incomplete, and mixed with weak (and sometimes contradictory) solutions, as when the game theory is (re)proposed as a new (old) branch of evolutionary economics. In these cases scholars seem to forget that the construction and the solvability of the payoff matrixes is based just on the maximization of utility functions, and implicitly on the adoption of (reduction to) a single criterion of choice. On the other side the non-neoclassical approaches to choices are weak, especially when the multicriteria nature of choices is acknowledged and faced with the traditional or naive methods (see next section).

The question of multicriteria nature of human choices implies a critique as fundamental as those of Simon, because it demonstrates the impossibility even to build the utility (or welfare) function. Indeed, the impossibility to build an aggregate function at all. In this sense, this critique is more fundamental of Simon's one, and at the same time reinforces that of Simon. In fact, before questioning whether human beings can be maximizers, one should suppose that the function to be maximized does exist (or can be constructed). Now, an aggregate function cannot, generally, exist, and consequently, of course, cannot be maxi- or minimized.

The question can be put this way. The multicriteriality means the condition to be constituted by many objective-functions, because each criterion equals a function. Thus, instead of a single function we have a vector of objective-functions, as follows:

$$V = \{f_1(x), f_2(x), \dots, f_n(x) / x \in X\}$$

where x is an alternative of X , the finite set of available alternatives. Now, the fundamental mathematical property of the vector V is that V is *not a function*, and it can

neither be reduced to a function, excepted by means of some restrictive conditions which have to be supposed. Indeed such conditions, in order to build a function, reduce the multiplicity of criteria to one, making the reduction to uniqueness. These conditions result in cutting $n-1$ criteria, so to have just one criterion.

On the other hand, being not a function, V cannot of course be maximized or minimized. Consequently, if a choice is multicriteria, it cannot be dealt by NET. In fact, NET deliberately neglects the multiple criteria nature of human choices or tries to manipulate that nature in such a way to neutralize and deny it. This is just what do traditional and naive methods.

Pragmatic and Fictitious Methods

Besides the very simple counting of advantages and disadvantages of each criterion, hoping that they eventually converge to some consistent positive or negative direction for each alternative, the traditional solutions can be grouped into two classes:

1. methods based on adaptation and learning, which are basically three: rule following, routines following and best practices imitation;
2. methods based on the construction of a super-function multi-attribute utility theory, multi-objective linear programming, goal programming, and naive methods.

The methods of the first group are based on some limitedly intentional learning function, and they suffer of defects of empirical learning. They are based on the hypothesis that the world replicates invariantly, at least for those aspects under consideration. Therefore, to the extent the environment is significantly new, these methods fail to succeed. At least, in this case they would give solutions largely far from what potentially could be done, that is, far from satisfactory choices.

The methods of the second type, instead, hide a true unicreriality under the appearance of the multicreriality. By adding some mathematical constraint, which is a very well known and old neoclassical methodology, they are based on the reduction of multiplicity to unity (Laise & Valentino 2000). This way they come back to the neoclassical approach, which presuppose just one criterion. The typical method is the multi-objective linear programming, which is a sort of sub-set of multi-attribute utility theory. It assigns weights to any criterion and than aggregates all the criteria in a single one. This way a single objective-function is obtained. However these methods present two relevant defects. First, they imply the invariance of marginal rates of substitution between the criteria, and second, they can lead to paradoxical solutions, as happen to any application of average weight methods when the standard deviation (the dispersion around the average) is high. The very pragmatic and diffused method of assigning weights to any criterion and compare the sum obtained for each alternative is nothing else than a simple application of multi-objective linear programming.

The other main method belonging to the second group is the so-called naive method, which consist in selecting, between the many, a single criterion as the objective-function, and in assuming the other criteria as constraints. The defect is that the solutions change sharply depending on which criterion is chosen to represent the objective-function and which criteria are chosen as constraints. Moreover, if the criteria are genuinely independent and meaningful, there is no reason to make any distinction between criteria and constraints. They are all criteria. Thus, if we want to avoid an arbitrary choice, we must reject this method.

In summary, no any traditional method is satisfactory, because they are weak, limited or defective. However there is an alternative, represented by the outranking methods, as that showed in next section.

The Outranking Methods of Multicriteria Decision Making

The outranking methods represent the most effective multicriteria methods, because they lack the defects of the aforementioned traditional ones, and are as well rational (formal and robust) as the standard logic of choice, that is, as NET. Actually, they could be called the true non-standard logics of choice. In order to show these methods, which indeed are an entire class, we choose those based on the French school of operations research (Roy 1985; Roy & Bouyssou 1993; Vincke 1992), which are also performed through a specific software (Roy & Bouyssou 1993).

The choice of the satisfactory method to make and evaluate technology policy in multicriteria terms can be summarized as follows. It is given a set of alternative policies:

$$A = \{a_1, a_2, \dots, a_n\}$$

Let be a set of assessment criteria:

$$G = \{g_1, g_2, \dots, g_n\}$$

Problem: taking into account all the criteria, select the satisfactory technology policy, i.e. the alternative that outranks the others. In order to draw up an operational procedure to solve this problem, the following pages will use the ELECTRE multicriteria choice methodology, produced by the French school of operations research. Since this is not the place to go into the technical aspects of the ELECTRE methodology, a numerical example is used to illustrate its potential.

A numerical example of multicriteria choice. Of course there are many possible technology policies, depending on the goals of the local, regional, national or international institution which plans the policy. Limiting the choice just to SMEs, according to recent orientations of EU, the following criteria could be set:

- promoting the supply of real services (information, quality certification, etc.),
- giving selective financial aids,
- giving non-selective financial aids,
- incentivizing enterprise creation,
- increasing the survival rates by tutoring new firms,
- incentivizing SMEs networking
- incentivizing SMEs exports,
- incentivizing SMEs innovation
- incentivizing ICT diffusion in SMEs.

Even if the methodology of outranking methods could support the comparison of all these alternatives, in order to simplify the numerical example let suppose to limit to the following set:

$$A = \{a_1, a_2, a_3, a_4\}$$

where:

- a_1 = incentives to SMEs innovation (INN);
- a_2 = incentives to ICT diffusion in SMEs (ICT);
- a_3 = incentives to SMEs networking (NTWK);
- a_4 = incentives to SMEs exports (EXP).

As for alternatives, even selecting or evaluating criteria can be numerous. Again, in order to simplify the numerical example, let assume the following set of criteria:

$$G = \{g_1, g_2, g_3, g_4, g_5\}$$

where:

- g_1 = SMEs productivity (SMEPRO)
- g_2 = net enterprise creation (NEC)
- g_3 = average size distribution (ASID)
- g_4 = net employment creation (NEMP)
- g_5 = survival rates (HSR)

Both alternatives (policies) and criteria can be represented by a general multicriteria matrix (tab. 1):

Tab. 1 General multicriteria matrix

Criteria Policies	SMEPRO (g_1)	NEC (g_2)	ASID (g_3)	NEMP (g_4)	SR (g_5)
INN (a_1)	$g_1(a_1)$	$g_2(a_1)$	$g_3(a_1)$	$g_4(a_1)$	$g_5(a_1)$
ICT (a_2)	$g_1(a_2)$	$g_2(a_2)$	$g_3(a_2)$	$g_4(a_2)$	$g_5(a_2)$
NTWK (a_3)	$g_1(a_3)$	$g_2(a_3)$	$g_3(a_3)$	$g_4(a_3)$	$g_5(a_3)$
EXP (a_4)	$g_1(a_4)$	$g_2(a_4)$	$g_3(a_4)$	$g_4(a_4)$	$g_5(a_4)$

Although the values assigned to each alternative by each criterion can be either qualitative or quantitative, suppose now a range of 1 to 5 score. The result is a multicriteria numerical grid (tab. 2).

Tab. 2 Numerical multicriteria matrix

	SMEPRO	NEC	ASID	NEMP	SR
INN	1	4	3	3	4
ICT	4	3	3	5	2
NTWK	3	4	4	4	3
EXP	5	1	1	2	1
weight	0,2	0,2	0,2	0,2	0,2

We can see that the multicriteria grid is now surrounded by a line containing the weights that the evaluator or the policy maker assigns to each criterion. We have the hypothesis that the criteria are equally relevant, i.e. that each criterion has the same importance as the others. This “border” operation is necessary in order to identify the satisfactory policy, because the evaluator or the policy maker must explicitly express the importance to be assigned to each criterion. Implicitly, NET would assume the value of the welfare as the only meaningful criterion, and thus, would assign 100% to it and 0% to all the others. The maximization of such criterion would be the only right algorithm, and the only rational choice.

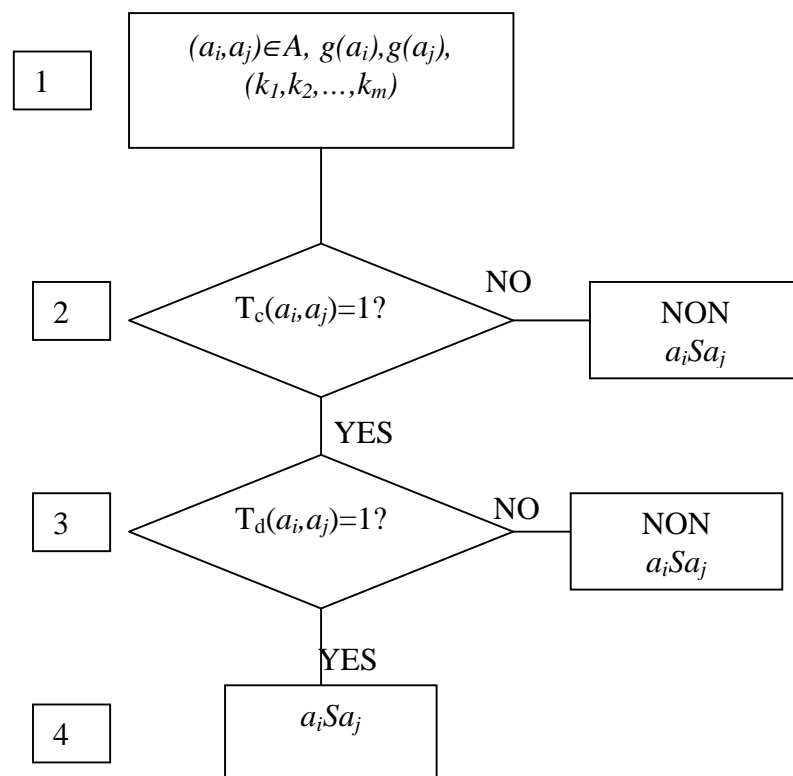
In the numerical example here submitted, the reader can see that apparently no any alternative (policy) emerges as the best or the dominant one. There is no optimum neither maximum. In such a situation, the evaluator or the policy maker would choose through some of the naive methods: likely (s)he would assign the weights to each criterion, multiplying per the values of each alternative. This way s(he) would get a

single column, which would represent a sort of “super-criterion”, what we called the “super-utility” function. S(he) would apply (likely unintentionally) the multi-attribute utility theory methodology, suffering all the relative defects and constraints. The outranking methods can avoid them, and give a satisfactory solution, consistent with a behavioral (and evolutionary) theory of decision.

The algorithm of outranking methods works through the following steps (fig. 1):

1. giving scores to each alternative under each criterion [$g_j(a_i)$] and giving weights (k_j) to each criterion, in order to have 100% in total;
2. building a concordance matrix, which measures the extent to which the alternative a_i are preferred to alternatives a_j ; and building the corresponding concordance test (T_c);
3. building a discordance matrix, which selects the choices that are non comparable or denied or in a state of too strong (unacceptable) conflict, and building the corresponding discordance test (T_d);
4. building, through the joint application of concordance and discordance matrixes, the outranking matrix, and building the corresponding outranking relation (S);

Fig. 1 Outranking method (flow chart)



We cannot now show all the steps of the outranking methods methodology (algorithm), because it would take too much space and move the attention far from the main goal of this paper. The whole procedure is shown in the case of finance (Laise & Valentino 2000), strategy (Biggiero & Laise 2001a), and organizational behavior (Biggiero & Laise 2001c), while the theoretical framework, with the demonstration of the relevant theorems, is developed by the French school of operations research (Roy 1985).

The objective of the procedure is to get an outranking matrix, where the alternatives (policies) are compared as in a tournament, that is, where the comparison occurs through dyadic relationships. However, it is not necessary to have completeness, that is, some relationships could be absent. If the cell is filled by 1, it means that the alternative indicated in the row outranks that indicated in column. If the value is 0 it means that the alternative is outranked by the other alternative, or that there is no relationship at all between the two alternatives. With reference to the data of this example, the outranking grid is as follows (tab. 3):

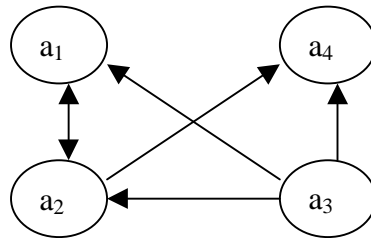
Tab. 3 Outranking matrix

	a ₁	a ₂	a ₃	a ₄
a ₁	---	1	0	0
a ₂	1	---	0	1
a ₃	1	1	---	1
a ₄	0	0	0	---

The promotion of networking between SMEs - the alternative (a_3) -, emerges as the satisfactory policy, because, on the basis of the assessment criteria considered $\{g_1, g_2, g_3, g_4, g_5\}$ and on the basis of the weights assigned at these criteria $\{k_1, k_2, k_3, k_4, k_5\}$, (a_3) outranks all the other alternatives, and is not outranked by any other. In the outranking grid, the line for (a_3) includes every "1", which means that strategy (a_3) beats (outranks) all the others, while the column for a_3 includes every "0", i.e. alternative (a_3) is not beaten by any other. This suggests that incentivizing the networking of SMEs is the satisfactory technology policy, because it outranks the others. The incentivizing of innovation (a_1) and the incentivizing of the ICT diffusion (a_2) are in second place in equal position. Finally, the promotion of exports (a_4), which does not beat any other strategy, is at the bottom of the ranking, while is beaten by (a_3) and by (a_1) and (a_2).

This matrix represents a directed graph, where the direction of an arc indicates the outranking relationship. This result can better be seen in the outranking graph (fig. 2) associated with the outranking grid. As one can see, the set is neither transitive nor complete.

Fig. 2



Theoretical Implications

There are a number of theoretical implications. The most important one is that for no reason at all NET is still needed as the theoretical background, because the impossibility to treat technology policy as a unicriterial problem crowds out NET. Indeed, this holds for any kind of human choice, because they are generally multicriteria ones. Thus, NET should be rejected as a theory of socio-economic decisions at all. This is a more general result of our discussion.

Of course NET can be criticized, and eventually rejected for a number of other reasons, as evolutionary economists, some industrial economists and management scholars have done. However, we believe that our arguments are much more fundamental, because attack the core of NET: the utility or the welfare function, which is its correspondent in the field of economic policy. In essence, our thesis is that the impossibility to use NET to choose or evaluate the technology or the industrial policy does not depend only on the existence of market failures, but, much more radically, on the fact that NET cannot neither frame the issues under evaluation, because they are multicriterial. In other words, it is not “simply” a question of disputable prescriptions derivable from the theory, but just of the impossibility to deal with the issues.

After these statements one could reasonably wonder whether the outranking methods, which succeed in facing multicriteria problems, can be linked to some theoretical framework different from NET. The answer is definitely positive: BET, and its evolutionary developments, is perfectly compatible with the outranking methods. Even more, they can represent the true and solid formal tools of BET. They can fill the space left by NET in terms of theoretical robustness, space which many theorists complain

because of the lack of consistence and the plenty of confusion of the unorthodox approaches and the management sciences. The theoretical proliferation of these fields creates an unsatisfactory feeling, which sometimes pushes scientists and policy makers to refuge in the certain and solid world of NET. The outranking methods constitute a valid and promising perspective, perfectly able to fill the formal gap between NET and BET.

A further consequence is that, for the basic nature of BET is in the systems theory (Biggiro & Laise, 2001b), BET and outranking methods are the best candidate to deal with system failures in technology policy. They can be effectively taken into account by the outranking methods. It is enough to frame appropriately the choices under investigation. Once escaped from the view of a world of (quasi) perfectly rational agents who maximize, it is normal to cope with a world of market or system failures. Indeed they do not appear any more as failures, because the failure is the norm and the optimum is the exception. Besides the fact that, rigorously speaking, even in NET it is rather meaningless to speak about market failures, because the failures can be recorded and measured in reference to a perfect (optimal) world, and no human being has this property, the concept of failure a fortiori changes its meaning in a BET perspective. In a world of satisfactory choices, these are just more or less temporally and locally appropriate.

Policy Implications

Among the many policy implications, we can here briefly address just a few. The concrete tools to choose and evaluate the technology policy changes: no more using marginal costs, but accounting and estimated costs computed by the outranking methods, and other kinds of simulation models, as genetic algorithms, neural nets, etc. The second consequence is that, for outranking methods are highly interactive, they allow to reduce the gap between policy makers and policy technicians. The frame of the question and the sensitivity analysis foster both to work together. The third consequence is that the policy should no more justify its place and role, because no theoretical arguments for the chimera of free market or “laissez faire” can dominate or constraint the interventions. Fourth, recent evolutionary approaches, as the national/regional systems of innovation, receive a sounder theoretical ground, and concrete tools to choose and assess technology policy, or any other kind of policies.

Through the sensitivity analysis the outranking methods allow the construction of simulation models. Researchers and consultants can select the relevant variables, and the policy makers can define its weights. Than they can jointly adjust variables and weights, as well as concordance and discordance thresholds, in order to find the appropriate (satisfactory) solutions (alternatives). Indeed the holding of concordance and discordance thresholds (tests) play the role of defining the desired levels of aspiration in the behaviorist model (Simon, 1969, 1983).

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