Agent-based modeling techniques for development economics*

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Abstract

In this article I discuss the potential role of agent-based modeling techniques in development economics. Development economics has recently seen a strong rise of randomized field trials aiming at understanding in depth what works in specific contexts. At the same time, there is a debate on how theory should adapt to this new approach and its findings. I argue in this paper that agent-based modeling techniques are a promising alternative to the traditional modeling techniques, as they can easily incorporate the non-standard findings of the experimental literature. Moreover, I emphasize the opportunity of a mutually beneficial interplay between experiment based empirical research and agent-based models.

Keywords: development economics, agent-based modeling techniques, randomized field trials, experimental economics, poverty reduction

JEL-Classification: B40, C63, C93, I30, I38, O12, O22

1 Introduction

This article aims at contributing to the debate on the role of theory in development economics, particularly in the light of the increasing role of field experiments. I discuss what role agent-based modeling techniques might play in the development of a new theory for development economics. Before entering into the details, I first introduce the ongoing debate on the use of field experiments and the role of theory.

The use of experiments in the empirical literature has increased sharply of the last years. This increase is particularly marked in development economics, where randomized field trials (RFT) became very popular. Besides development economics there are also many experiments conducted in the field of behavioral economics. Common to the two fields is the goal of understanding in depth very particular behaviors of individuals. The focus moved from the big macro-questions to concrete problems, especially in development economics. In their book *Poor economics* Abhijit Banerjee and Esther Duflo argue that poverty reduction methods should be evidence based

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and that such evaluation is best achieved through field experiments (Banerjee and Duflo, 2011). Randomized field experiments overcome critical problems of identification and can therefore be considered the gold standard in policy evaluation (Duflo, 2006; Duflo et al., 2007).

While most scholars accept the high value of field experiments for the estimation of causal effects[1], we can also find some critical voices with respect to the strong influence of this method in development economics. The most common critique concerns the missing external validity, thus the possibility to extrapolate the result from an experiment to other situations (Mookherjee, 2005; Bradhan, 2005; Basu, 2005; Rodrik, 2008). The argument is that experiments are inherently small and focus on a particular question. Thus, they might not capture some general-equilibrium effects and the results might depend on the circumstances of the experiment.

The defenders of the experimental approach argue that external validity can be achieved through replications of the same experimental setting in different regions and over time. The argument is that in case of finding similar results everywhere, one might think that it is generally valid[2]. However, similar to the critics do not directly question the usefulness of RFT, the defender are not saying that they solve all the problems using RFT. In fact, both Duflo (2006) and Banerjee (2005) argue that besides the experiments we need some theory. Both call for new body of theory which takes into account the challenges to the established theory made by experiments in the field of development economics and behavioral economics. Duflo (2006) calls the theory of behavioral economics rather a "collection of anomalies" and underlines the importance of finding a new coherent framework. Banerjee (2005) also argues that theory is important in order to ask the right questions in the experiments.

Thus, it seems that both the critics and the defenders of the randomized field trials have very much in common. They agree on the usefulness of experiments but see also the need to put emphasis on the generalizability, for instance through the development of a new body of theory. Two requirements seem to be clear for this new body of theory. First the theory must be able to take into account the result from experiments. Rodrik (2008) speaks in this respect of a more *diagnostic* strategy than the traditional *presumptive* approach. A second element is the need of a flexible theory that can be adapted to the particular situations. Rodrik (2008) argues that in terms of reforms we have to move away from the "one-size-fits-all" strategies and towards context-specific solutions. This is equally true for theory. In this debate there seems to be a consensus on the need of theory and a vague sketch of what the theory should look like. In contrast, relatively little is said about the techniques to be used. As in the empirical literature with the use of experiments, it might be necessary to start using innovative techniques also in

[1] Nevertheless, there are also some critical view on experiments. For instance, McMillan (2007) discusses a series of potential problems that might reduce the quality of estimates.

[2] Rodrik (2008) has a similar argument. However, he argues that this will be problematic as top journals are unlikely to publish several time the same experiment with only very small changes. Thus, he argues that external validity should be already taken into account from the beginning and not only achieved through a multiplication of studies.

theory in order to satisfy the requirements.

In this essay I argue that agent-based modeling techniques can be one of the ways to go. Agent-based modeling techniques can make models more context-specific and allow the modeler to take into account the anomalies found in experiments. The core idea of the agent-based modeling approach is a bottom-up modeling of the economic system. Bottom-up means that the modeler starts with the behavior of agents and their decision processes. The approach aims at using as little assumptions as possible. The downside of this is that a very detailed knowledge is required on the actual behavior of agents. Nevertheless, this knowledge is precisely gained through the experimental approach and agent-based models can help to put the pieces together. I would therefore say that the experimental approach and theoretical models using agent-based techniques are mutually beneficial. To make this clearer, I proceed as follows.

First, I introduce the notion of agent-based modeling, which does not have a uniform definition. I particularly focus on the important elements for development economics. In a second step I then discuss in detail the different advantages and disadvantages of the approach - again particularly focusing on developing economics. I use an example of schooling decisions to illustrate these points and sketch how agent based models might be useful. Regarding the disadvantages I show that most of them are more challenges than unavoidable disadvantages and that the growing literature of experimental economics and behavioral economics represent an opportunity to overcome these challenges. Finally in section 4 I sketch the idea of an iterative research approach, where insights from empirical evidence is used as ingredient to refine the theoretical models. They are then used to evaluate potential interventions ex-ante and serve as ingredient for posterior experimental research.

2 A brief introduction to agent based modeling techniques

A first important point about agent-based modeling techniques is that it does not represent *per se* a different theory. It is important to see agent-based modeling technique as a tool or technique. We could well imagine using this technique for standard models in economics as well, even though it would probably not make much sense, given that we already have the analytical solutions for the existing models. Thus, agent-based models are simply a way to overcome some problems when the analytical approach is no longer feasible[3]. As I will discuss further below, this might well be the case when trying to incorporate the insights from the experimental approach in development and behavioral economics.

Let me now briefly introduce the main ideas of the agent-based modeling techniques. Even though there are different ways to define agent-based models, there is a common key element: the agents. Agents are defined by Epstein and Axtell (1996) as the "people of artificial societies" featuring "internal states and behavioral rules"[4]. *People of artificial societies* must be

[3] Miller and Page (2007) provide a very comprehensive discussion on these differences.

[4] There are different ways to define agents. For instance Wooldridge and Jennings (1995) define agents around

understood in the broad sense, as agents can also represent firms, governments and other entities. Different types of agents can be present in a single model. *Internal states* describe the characteristics of an agent at a given point in time. They can be stable of time or evolve. *Behavioral rules* describe the decisions and actions of agents. They can take very different forms and levels of sophistication, starting from simple deterministic rules up to highly sophisticated optimizations. The behavioral rules can use as input the state variables of the agent itself but also of other agents (if the information is revealed) or from the environment. The environment in which agent are "living" can also be modeled. The model is then solved by letting various agents interact and evolve.

In order to better illustrate the elements just described, let us imagine a very simple model of schooling decisions. Assume that we want to model the decision of children to continue at school or to drop out and enter the labor force. We can follow Becker (1964) and use the human capital approach. The idea of this approach is that education is beneficial for the individual as it increases future earnings. At the same time it is costly in terms of foregone earnings while studying and because of the effort the individual has to put in education. Both the cost and the benefits depend on the characteristics of the individual. The individual drops out of school when the marginal cost of education becomes bigger than the marginal benefit. In the traditional modeling approach, we can optimize the behavior of the individual by maximizing the inter-temporal utility function. The individual in the Becker-model corresponds to the agent in the agent-based modeling approach. The *state variables* would include for instance the endowment, the ability and past experiences in school. The *behavioral rule* would consist in computing the marginal cost and the marginal benefit of continuing in school. The agent would then continue as long as the marginal benefit is higher than the marginal cost. Thus, in the agent-based modeling approach we put ourselves in the shoes of the agent and do not look at the world from above. As long as we stay in the Becker-type world with clearly defined utility functions and fully available information, the traditional approach with analytical solutions is likely to be better than agent-based modeling techniques. The strength of agent-based modeling techniques is coming to play when the conditions are less clear or when we would like to add different types of behaviors. We could for instance put agents into an environment with different school availabilities and different school qualities. Another modification could be that people do not fully know the returns to education they might expect, but they can observe the outcomes of some peers. By adding such elements to the model, the traditional modeling approach reaches its limits very quickly. In contrast, agent-based modeling techniques are very flexible in this respect and can easily provide solutions. In the next section I will go through the main advantages and problems of agent-based models.

four features: autonomy, social ability, reactivity and pro-activity. Gilbert and Troitzsch (2005) base their definition on Huhns and Singh (1998) and refer directly to self-contained programs that can control their own actions based on their perceptions of their operating environment

3 ABM in development economics

Now that we briefly introduced agent-based techniques, we can move to the discussion on its usefulness for development economics. As for all tools there are advantages and disadvantages, both of which I will discuss in this section. Moreover, it has to be noted that other methods might share some of the advantages outlined hereafter. Thus I do not claim that ABM is the only way of achieving these points.

3.1 Advantages

To discuss the advantages of agent-based methods for development economics, let me consider the following three groups of arguments: heterogeneity, interaction and information and flexibility. I will discuss each of them individually in the following sections. A more general discussion of advantages of agent-based models for social sciences can be found in Miller and Page (2007) and Gilbert and Troitzsch (2005).

3.1.1 Heterogeneity

Heterogeneity is a crucial concept in economics in general and probably even more in development economics. Individuals in a given region are not all alike, but differ in many ways. While almost all traditional models consider to some extent heterogeneity, the number of dimensions in which individuals differ from each other is very limited, mostly there is only one. This simplification can be good as long as the researcher is primarily interested in the aggregate outcome which does not depend on other (omitted) dimensions of heterogeneity. However, when we are interested in the disaggregated outcome, taking into account all relevant dimensions of heterogeneity becomes vital. Agent-based modeling techniques can handle heterogeneity in multiple dimensions fairly easily. As in the empirical literature on impact evaluation, it might be more interesting to consider heterogeneous treatment effects than just assuming that either all agents react the same way or to focus on the average effect.

Let me take again the example of the schooling decision from before. We might think of multiple heterogeneity in gender, family background, ability and so on. However, the possibilities to deal with more heterogeneity when using agent-based models is not limited to heterogeneity in state variables. We can also include heterogeneity in behavioral rules. There is no reason to assume *a priori* that all individuals in a population use the same behavior to take decisions. We could well imagine that some individuals truly optimize their schooling decisions while others simply aim at getting as far as they can. Again other individuals might simply copy the behavior of peers. Traditional tools offer very limited possibilities to include different behavioral rules simultaneously in the same model.

The downside of adding more heterogeneity to a model in order to better approach the reality is the risk of creating a sort of a black box. I will come back to this issue in section 3.2.2.

3.1.2 Interaction and information

Besides the simple inclusion of multiple heterogeneities the possibility to consider interactions between agents is another major advantage. The decision of one individual is not independent of what other people around are doing. Interactions can also be included in more traditional models. However, agent-based models allow the researcher to design such interactions with much more detail. For instance, one might think of limiting the interaction to a subset of the population, e.g. some neighbors.

Directly related to the interactions is the issue of information agents have. All decisions that individuals make are based on pieces of information. Traditionally we assume perfect information or at least well defined imperfect information. The researcher defines exogenously who knows what and normally the information issue is limited to asymmetric information. This is very important but we might want to go even further. Take again the information of the schooling decision. Even if we assume a standard human capital model where people get educated until the point where the marginal cost of education equals its marginal benefit, we might face a problem of information. It is relatively hard to believe that everybody knows about the actual average return to education for each level of education[5]. However, it is perfectly imaginable that people observe individuals around them. If the daughter of the neighbor went to high school and now has a well-paid job, then incentives are probably higher to attend high school than if she would be unemployed. Thus, local information can be a crucial element in understanding differences in the schooling decision. Banerjee and Duflo (2011) discuss this issue as well and argue that misperception of the return to education can be critical and result in an underinvestment in education by the poor and eventually create a poverty trap. The misperception of the returns to education can simply be due to a lack information and because the information people are using is based on local information.

Agent-based modeling techniques allow the researcher to include such differences in the available information set easily. However, detailed information on the availability of information and its use are required. Simply assuming that people know about the population average return to education would definitely be easier, but probably not appropriate. Hence, the additional possibilities in the modeling techniques also bring additional difficulties. I will discuss this point in more detail in section 3.2.3

3.1.3 Flexibility

Probably the most important argument of Banerjee and Duflo (2011) is that development economics - or at least poverty analysis - should focus on concrete problems and not on the big questions. Instead of using large scale survey data or even macro data including various coun-

[5] We could go further and ask if anybody knows this truly. Card (2001) discusses various econometric issues related to the measurement of returns to education and argues that even in the empirical literature many of the issues are not correctly addressed.

tries, they focus on randomized field trials to answer very specific questions. These questions are generally on a much smaller scale in terms of size and geographical coverage but definitely not in terms of importance. Just like their empirical zoom on specific problems, we might want to zoom in as well in theory. This is moving from a general theory which is supposed to be applicable everywhere to very context specific models. Such models can for sure share some common bases but they should also be adapted to the specific context. Let me use the example of weather forecast to illustrate this point. Meteorological models all around the globe use some knowledge on common phenomena influencing the weather. However, in order to correctly forecast the weather at a specific place, the models have to be adapted. This adaption is not only by adapting some parameters, but by considering some place-specific characteristics. This can be very similar in economics as well. Through experiments we might find some common behaviors and processes which are more or less stable across societies. In contrast, there might also be some elements which differ substantially from one place to the other. Cardenas and Carpenter (2008) discuss some lessons from behavioral economics for development economics. They provide a lot of information on experiments conducted in different places. While some results seem to vary very little from one experiment to the next, there are others which show substantial differences. Thus, there are good reasons to believe that economic models should be based on some common processes where possible, while allowing for substantial differences where needed. In this regard, agent-based models offer the researcher a very flexible tool. Let us take again the example of the schooling decision. The schooling decision is likely to be substantially different in an urban area as compared to a remote village. Not only the supply of schools is different and therefore influencing the possible choice, but also the alternatives to schooling and the post-schooling opportunities vary. Hence, it becomes very important to include such context-specificities. Agent-based models allow the researcher to model not only the individuals, but also the environment in which they are living. The most extreme inclusion of context specific elements is probably achieved when actual geographic data (GIS) is added to model the environment. Less detailed implementations of various environments are also possible. However, the flexibility is not limited to the environment. In general, many changes in the model can be easily done and the results are obtained immediately. In contrast to analytical model, the marginal cost of some additional features in the model is very low. There is no need to derive again all the analytical solutions.

The higher flexibility in the development of the model but also in the use and adaption of the main model to specific situations increases the number of potential findings from a model substantially. The impact of each parameter in each possible combination of other parameters can be analyzed, different agent types can be combined, the environment adapted and so on. This multiplication of results which cannot be summarized by a couple of analytical solutions introduces a certain risk of getting lost. I will discuss this issue and its remedies in section 3.2.2.

3.2 Disadvantages and challenges

In the previous section I discussed the main advantages of agent-based modeling techniques in the field of development economics. Actually most of the arguments apply also to other fields of economics. After having seen the benefits of the approach, let us now have a look at the cost. Agent-based models also have disadvantages, even though most of them can rather be seen as challenges rather than unavoidable disadvantages.

3.2.1 No analytical solution

Probably the most repeated critique of agent-based models is the absence of analytical solutions. It is true that agent-based simulation techniques do not provide the researcher with an analytical solution. It would be wrong to argue that analytical solutions are not desirable. No, in fact, we should rather look at the cost to get them. Miller and Page (2007) discuss this question as a trade-off between precision and flexibility. They argue that the cost of the precision of analytical solutions is "often a lack of flexibility in the phenomena that we can explore". Thus, the argument is rather that in some cases the cost of achieving analytical solutions is much higher than its benefits. If we have a model which cannot be solved analytically, we might take different approaches. One way is to simplify the model until it becomes again possible to solve analytically. The risk of this solution is that the model we end up with might be quite different from the real world, because it requires a lot of simplifying assumptions. The other possibility is to change the way we want to solve the problem and to accept non-analytical solutions. Once we accept such solution, we can keep much more complex models and get results from them. The cost of loss in realism due to the willingness of getting analytical solutions might be higher than the loss of getting analytical solutions. In the end, this comes back to the famous quote of Carveth Read saying that *"It is better to be vaguely right than exactly wrong"* (Read, 1914, p. 351).

3.2.2 Risk of black-boxes

Another critique I often hear when talking with people is that agent-based techniques create black boxes. This means that the model becomes increasingly complicated and complex and that in the end we do not know any longer where the result comes from. This critique is fundamental, very relevant and directly related to the issue of analytical solutions. The possibilities offered by the agent based methods bear the risk that too much is put in the same model. However, a model always remains a simplification of the reality. The ultimate goal cannot be to reproduce reality one by one. It is important to find a well-chosen intermediate level between too simplistic models and incomprehensible black-boxes. When increasing the complexity of models, two elements of the research effort must receive more attention: the description of the model and the presentation of the results.

Description of the model

By adding more and more elements to a model, the readers and sometimes even the modelers get lost. It becomes crucial to describe the model in a very clear and structured way. It has to be clear what the model does, what is assumed to be exogenous, endogenous and so on. A useful tool to achieve such clarity is the so-called *Overview-Design-Details (ODD)* protocol developed by Grimm et al. (2006) and updated by Grimm et al. (2010). This protocol consists in providing first an overview of the purpose of the model and the core elements. In a second step details on concepts used are introduced and in the last part the technical details are explained. Such a protocol allows the modeler to highlight how rigorously the model is developed and implemented and ultimately it helps very much to increase the credibility of the model. Additionally, the ODD-protocol favors also the reproducibility of agent-based models.

Presentation of the results

After well describing the model and its elements, it is crucial to present the results accordingly. As there are no analytical solutions, much attention must be paid on how to best present the results. In this respect it is important not only to show the main variable of interest, but also to pay some attention to other processes included in the model. It must be clear that the model does not only provide reasonable results for the main question, but also for the other elements included. An important element of the results are sensitivity analyses (Gilbert, 2008). Ideally the model is directly followed by empirical validation. However, putting both the development of a whole agent-based model and a convincing empirical validation in one article might be too much. In section 4 I discuss how the experimental approach can help us to validate the models.

3.2.3 Need for detailed knowledge on behavior

The last disadvantage I would like to discuss is the requirement of detailed knowledge on the behavior of agents. Actually, in this case I definitely prefer the term *challenge* over disadvantage. Some authors like Miller and Page (2007) put it even as an advantage. Agent-based models are highly process-oriented, which means that the processes have to be modeled in detail. In contrast, traditional tools model essentially the process outcome, for instance the final decision. However, by zooming in and looking at the details of the process, many questions arise. For instance, in which order do agents decide, what information do they have and what information do they use in their decision? Let me illustrate such questions with two examples. First, consider again the schooling decision model from before. An important piece of information in order to decide until where to enroll in school is the knowledge about the abilities of the child. However, to what extent does the individual actually observe its ability? Could it be biased by wishful thinking and optimism as found by behavioral economists (Thaler, 2000)? Another question is even more basic: who decides on schooling, the parents or the child and at what age the decision taker changes? Finally, in the presence of siblings, how does that impact the decision?

Many other modeling techniques could also include such details, but often they don't do it. By not modeling such details, we implicitly assume some default processes (Miller and Page, 2007). However, precisely these details can matter in the end, especially when we are interested in the individual outcomes and not only the population average.

Another illustration might further clarify this challenge. Let us take a model of an informal credit market where individuals can lend to and borrow from each other. Using a traditional modeling technique we would easily find some equilibrium conditions which satisfy the welfare theorem. However, Epstein and Axtell (1996) show in their now famous *sugarscape* model that even in a very simple setting the results obtained from an agent-based model where they let agents interact differ substantially from the equilibrium result. This can be due to very fundamental questions on the interaction of agents and the processes. For example, the standard model implicitly assumes that everybody can and wants to deal with everybody else in the model. This needn't be realistic. For instance, one might ask whether in an informal market we can really trade with everybody or just with people within our network (e.g. families, friends, co-workers, etc.). If we just want to consider a network, how should we define it? Moreover, what information about the borrower is revealed to the potential lender? Does the potential lender give the credit immediately or does he or she wait and see whether somebody else is ready to pay higher interest rates? Who has the bargaining power? We could still add many more questions on how the process of money lending between two individuals should be modeled.

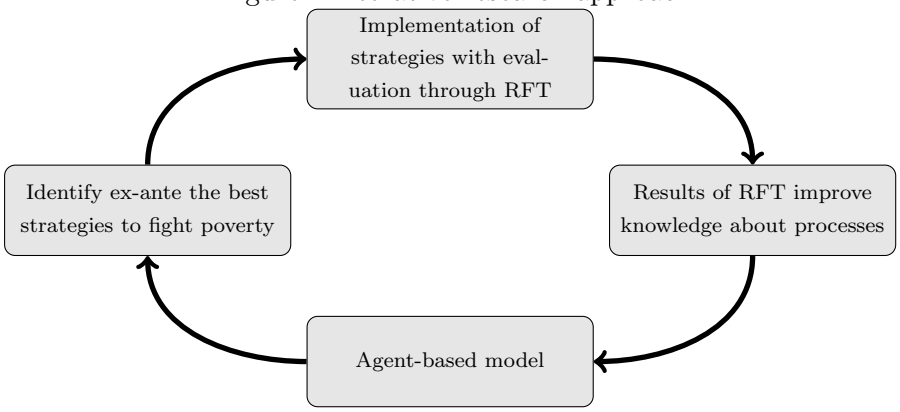
As highlighted by Miller and Page (2007) and confirmed by my own experience, being confronted with such questions while programming agent based models can be very enlightening but also frustrating. Enlightening because we realize how many processes we generally ignore in traditional models and frustrating because of the fact that to many of the emerging questions we do not have a clear answer. In the next section I discuss how this problem might be overcome. I show that the increasing number of social experiments and randomized field trials helps us to model these processes and how in turn the resulting agent-based models can be beneficial for the empirical research.

4 Towards an interplay of applied theory and applied empirics - an iterative research approach

After the introduction of agent-based methods in general and the previous discussion on advantages, disadvantages and challenges of agent-based methods in development economics, I now turn towards a potential role of such models. As I just highlighted, agent-based modeling requires a large amount of knowledge about processes. How do people decide? What information do they take into account? With whom do they interact. These questions are precisely the questions the empirical literature can answer thanks to the focus on concrete questions and the use of randomized field trials. Randomized field trials sharply improved the knowledge on how

people actually act and react. We can therefore say that these research efforts represent an opportunity to better develop agent-based models. However, developing agent-based models is not the ultimate goal, especially not in the field of poverty reduction. The ultimate goal is to develop models that enable us to find the best strategies to fight poverty. Figure 1 illustrates, how this goal can be achieved.

Figure 1: Iterative research approach



Let us start at the top of the illustration. We have a randomized field trial to study a particular phenomenon. From this experiment we learn more about how people act, react and decide. We can then use this knowledge along with knowledge from other studies to build an agent-based model of the phenomenon. This will almost surely raise new questions on the exact processes. At this stage the idea would be to make a couple of assumptions on how the process might look like. Several alternatives can be implemented at the same time and potential policy responses can be evaluated. In a next randomized field trial we can then test the different assumption and/or implement the best strategies identified in the ex-ante evaluation. Thus the idea is that by each iteration, the knowledge of the phenomenon and on possible policy responses increases and that the two approaches feed themselves mutually with information.

5 Conclusion

In this article I discussed which role agent-based modeling techniques can play in development economics. I argue that the recent increase of empirical analyses focusing on concrete phenomena and processes represent an opportunity for this modeling technique. The main reason is that agent-based modeling requires detailed knowledge about the processes underlying a phenomenon. This new strand of empirical research now provides us with this knowledge. The possibility to create agent-based models allows us to get closer to reality with the theoretical model, which will in turn be beneficial for the understanding of the phenomenon and the ex-ante evaluation of a large set of possible policy responses. By the use of an iterative research approach consisting in the interplay between empirical evidence based on experiments and the agent-based modeling,

we have the opportunity to advance our general knowledge and ultimately to improve policy responses.

The agent-based modeling technique is not a wonder-weapon to solve all problem of economic theory. There might be a large amount of problem in which this approach is not helpful. But there might also be some topics where agent-based modeling techniques can help us to reinvent the theory and get closer to what is found in the empirical and experimental literature. The ultimate goal of the experimental approach, the theoretical modeling and the interplay of the two remains finding the best way to fight poverty. Hopefully, the agent-based modeling technique can help us to get closer to this goal.

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