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ARTICLES

Thomas Malthus, Ester Boserup, and Agricultural Development Models in the Age of Limits

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Abstract Two competing models have served as the basis for agricultural development policies. One is based on observations and assumptions of The Reverend Thomas Malthus in late eighteenth century Britain, and the other from the Danish economist Ester Boserup in the mid-twentieth century. However, rational agricultural development decisions can only be made using a model that incorporates assumptions based on a technically appropriate model that takes into account the currently status of global systems. A new development model may incorporate elements of both Neo-Malthusian and Boserupian economic-demographic models, but because the world has changed substantially, it can be neither of them alone, nor a hybrid of the two models without significant expansion and refinement. The principles espoused by Malthus and Boserup can thus be used as the starting points in a dialectic argument to arrive at a new agricultural development paradigm.

Keywords Agricultural development · Modeling · Intensification · Malthus · Boserup

Introduction

Despite the massive input of development aid and other resources (Development aid peaked in 2013 at $136 billion (https://www.oecd.org/dac/stats/documentupload/ODA%202013%20Tables%20and%20Charts%20En.pdf), agricultural development has been refractory in much of the underdeveloped world. While there are many human-caused and 'natural' factors that have played some part in hampering development, there has been enough failure to warrant a fresh look at the assumptions upon which

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development policies and decisions are made. The United Nations Sustainable Development Goals for 2030 (http://www.undp.org/content/undp/en/home/sdgoverview/post-2015-development-agenda/goal-2.html), the Bill and Melinda Gates Foundation agricultural development program (http://www.gatesfoundation.org/What-We-Do/Global-Development/Agricultural-Development), the World Health Organization's eight Millennium Development Goals (http://www.who.int/topics/millennium_development_goals/about/en/), and the International Fund for Agricultural Development (IFAD) strategic framework (https://www.ifad.org/who/sf/overview), and many other major and minor development agencies all depend on one of two basic sets of assumptions about how development occurs, neither of which is adequate for solving current global development problems. Worst still, some of the strategic planning for development is based on a fusion of the two models, resulting in confusing and contradictory policies, priorities and plans. In this paper, the argument is made for re-evaluating the applicability of either of the two extant models for the global development challenges of the twenty-first century, particularly as the models have been applied out of context, and for rejecting hybrid versions of the Mathus and Boserup models as contradictory and thus self-defeating.

Thomas Malthus, in chapter 7 of his *Essay on the Principle of Population*, (Malthus 1798) states one of his key fundamental premises in tautological terms, 'The great law of necessity which prevents population from increasing in any country beyond the food which it can either produce or acquire, is a law so open to our view, so obvious and evident to our understandings, and so completely confirmed by the experience of every age, that we cannot for a moment doubt it.' In doing so, he essentially warded off serious challenges to his concepts of population and agricultural development for 176 years, until the publication of *The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Increase*, written by Danish economist Ester Boserup, who in the middle part of the twentieth century proposed an alternative view of agricultural development based on her experiences in rural India.

> 'There are two fundamentally different ways of approaching [the problem of the inter-relationship between population growth and food production]…On the one hand, we may want to know how changes in agricultural conditions affect the demographic situation. And, conversely, one may inquire about the effects of population change upon agriculture…To ask the first of these two questions is to adopt the approach of Malthus and his more or less faithful followers. Their reasoning is based upon the belief that the supply of food for the human race is inherently inelastic, and that this lack of elasticity is the main factor governing the rate of population growth. Thus, population growth is seen as the dependent variable, determined by preceding changes in agricultural productivity which, in their turn, are explained as the result of extraneous factors, such as the fortuitous factor of technical invention and imitation. In other words, for those who view the relationship between agriculture and population in this essentially Malthusian perspective there is at any given time in any given community a warranted rate of population increase with which the actual growth of population tends to conform…The

approach of the present study is…that the main line of causation is in the opposite direction: population growth is here regarded as the independent variable which in its turn is a major factor determining agricultural developments.' (Ester Boserup 1965)

The publication of Boserup's first book incited a quiet revolution 50 years ago that went almost unnoticed outside the narrow confines of a few academics, government officials, and Foundation experts interested in the disciplines of agricultural economics and rural development. Based on observations she had made in the field, Ester Boserup challenged essentially all of the accepted assumptions held at the time about the relationships between population, land use, and agricultural productivity (Turner and Fischer-Kowalski 2010). In *The Conditions of Agricultural Growth*, Boserup presented the argument that under increasing population pressure, land use patterns evolve from *extensive* methods (i.e. agricultural practices with long fallow periods covering a relatively large arable land area per person, or essentially slash-and-burn) to *intensive* methods (i.e. agricultural practices that use relatively small areas per person, made possible by short fallow periods or multiple cropping) as populations increase, and conversely that if there is a reduction in population, land use will revert to long-fallow methods (Ester Boserup 1965). She also observed that as more labor becomes available through increases in population, outputs can be increased by making land improvements, but at the cost of less free time for non-agriculture-related activities, and that technological innovation is dependent on population density (Boserup 1981).

At the time of Boserup's (1965) work, prevailing notions about agricultural development centered on the Malthusian concept that agricultural output of a given region, absent the option to emigrate, defines the limits of population. In this ideological environment of an assumption of zero sum, Boserup turned the ideological tables by suggesting that it is population itself that drives agricultural productivity and technological innovation. Her essay challenged the simple assumptions and concepts presented by Malthus in the first seven chapters of his 1798 essay *An Essay on the Principle of Population* (Malthus 1798), first by considering the evolution of land use systems as she had observed through her work for the United Nations, and secondly by constructing an economic model of the interaction of population with human productivity.

Since the publication of Boserup's work, scholars in the agricultural economics and development communities have tended to adopt one of two competing population and development positions. One position states that earth's resources are limited and that human populations have met or exceeded the ability of the planet to sustainably support the population, therefore populations must decrease to match the current level of production either through 'natural' means such as war and pestilence, or through policy interventions that reduce population growth (Neo-Malthusianism). In this world view, increasing populations degrade the social conditions of the human population, place natural or wild habitats under increasing stress, and increase the risk of systemic economic, ecological and social collapse on a global scale. The competing position claims that the development of human societies and economic systems depends on a 'demographic transition' to populations large and concentrated enough to require reassignment of land use from extensive to intensive, to free-up labor for technological implementation such as water transport systems or the use of draught animals, and to allow specialization of labor (Boserupianism). This view correlates technological innovation with increases in, or urbanization of, relatively large populations, and allows for those increases by adjustments in land use, technology implementation, and social organization.

An Argument for Rejecting Both Malthusian and Boserupian Development Models

Much has been made of the differences between Malthusian and Boseriupian views of the world, and both models have been subject to reviews and criticism (Grigg 1979; Krautkraemer 1994; Ross 1996, 2003; Turner and Ali 1996). There are two main reasons to reject both of these views of development, and to construct an entirely new model. First, neither model takes into consideration parallel political developments that affected land distribution, property rights, redistributional systems, development of trade, or many other variables that were occurring at the time, either because of a limited view of global conditions in the case of Malthus, or because of a strict adherence to economic principles in the case of Boserup. Thus both models are technically limited by the scope of their parameters. Secondly, although separated by almost 200 years, both models were constructed within a limited geopolitical and historical context, i.e. not the current geopolitical and historical context. No model can account for factors that occur post-construction, but the political, demographic, and industrial developments of the nineteenth century, and changes in global conditions since the early 1960's, such as the global decolonization movement, the Green Revolution, genetic engineering, climate change, macro-scale resource mobilization and depletion, health care expansion and innovation, and a global population in excess of seven billion are factors that must be considered if the welfare of the world's vulnerable populations is affected by policies arising from development models.

Technical Limitations of Malthusian and Boserupian Models

While there have been many criticisms and defenses of the ideas of both Malthus and Boserup, as well as more recent attempts to place their concepts within the same overall conceptual structure (Grigg 1979; Wood 1986; Krautkraemer 1994; Ross 1996, 2003; Ruttan 1999; Turner and Ali 1996), writing from the pre-Anthropocene epoch, the main problem with these development models is that they are narrow in scope and thus do not take into consideration the ability and willingness of societies to compensate for lack of resources, or resource competition by sacrificing quality of life or by 'borrowing' from the environment to meet immediate resource demands (Soby 2013). They do not take into consideration the finite resources of a closed (or semi-closed) system, nor what happens when such a system reaches its physical limit of intensification. Taking advantage of 167 intervening years, the obvious limits of the Malthusian model were addressed by Boserup herself by observing that land use intensification, technological innovation, and political organization introduce elasticity into agricultural systems.

Much of the contention between the two competing development model camps rests on the absence of a definitive argument that resolves the cause-and-effect relationship between population and development. Malthus depended on a limited (and perhaps disingenuous) historical narrative, including dubious assertions and examples from places he had never been, and had only heard about through anecdotal sources ('China seems to answer to this description [of a society induced to living on the edge of famine]. If the accounts we have of it are to be trusted, the lower classes of people are in the habit of living almost upon the smallest possible quantity of food and are glad to get any putrid offals that European labourers would rather starve than eat.' Or, 'Where a country is so populous in proportion to the means of subsistence that the average produce of it is but barely sufficient to support the lives of the inhabitants, and deficiency from the badness of seasons must be fatal. It is probable that the very frugal manner in which the Gentoos [Hindus] are in the habit of living contributes in some degree to the famines of Indostan [India].')

Boserup also made assumptions with little evidence to support them. For example, she largely ignored the impacts of industrial revolution on urbanization, transport, and industrialization of agriculture. She assumed that there is essentially no limit to extensive expansion or intensification, and most significantly she ignored the problem that population growth is dependent on excess food production. Boserup also did not attempt to explain why European settlers in North America (a subject covered in detail by Malthus) who were, in their view, faced with a largely unpopulated continent, continued to use intensive methods rather than the extensive methods that her model would have predicted. In her later book, Boserup attempted to provide demographic evidence to support her thesis by introducing the concept of autonomous population growth, referring to the 'more or less accidental surpluses of food' (Ester Boserup 1981). Boserup also stated that there is some unknown factor that drives some groups to increase population density faster than others, which eventually results in a permanent advantage for that group in agricultural, and presumably social development. Although she rejected the notion of autonomous technological innovation, that is, technological innovation in the absence of burgeoning and food-stressed populations (Boserup 1965), the unknown factor she sought to complete this model is likely some autonomous technological development that provides one group a decisive advantage over other groups. However, because this did not fit within her main hypothesis, she was unlikely to have recognized it. Boserup also stated that excess agricultural productivity is a precondition for urbanization, but how would excess productivity become available if her central thesis that populations drive productivity were true in all cases?

This leaves open the question of what happens when all of agriculture is intensive, or if regional agriculture is at the limits of intensification but still not adequate to meet the dietary needs of a population, a proposition not closely examined in either of Boserup's major works. Does a different set of rules apply? The most obvious criticism of the Boserup model is that poverty and hunger are most acute in the most densely populated regions (i.e. south Asia and parts of the

Middleast, sub-Saharan Africa, and Meso- and South America), whereas by the Boserupian model these should be the most prosperous, innovative, and productive. She also failed to examine what happens in a society that may have a large and concentrated population when the pace of population growth exceeds technological innovation, when a catastrophic event occurs, or when environmental degradation radically reduces the productivity of a previously fertile region. Erosion, salinization, desertification, and plant disease epidemics all occurred before the formulation of the Boserup argument, and all of which argue the limits of the assumptions underlying the model.

In her later work, Boserup conceded that limitations on food production, and on technology in general must certainly limit populations (Boserup 1981). ‘Population change is one of the determinants of technological change, and technological change is a determinant of demographic change… It is generally agreed that successive changes in technology had an important influence on population size, but opinions are divided concerning the type of technological change which had the greatest influence in different periods and in different regions. The opposite side of the interrelationship, the influence of population size on technology, has attracted less attention.’ Despite this reconsideration of her earlier work, and its failure to consider issues like global industrialization of agriculture, or what happens when fallowing is no longer an option, much of the current agricultural development argument continues to rest on the 1965 version of the Boserup model.

Development Models are Limited by Their Historical Context

Britain in the late eightieth century at the time of the Reverend Malthus was a time and place of uncertainty following the loss of the American colonies, the French Revolution, and the rise in industrialization, with its attendant economic changes that gave rise to a middle class with emergent political power. In fact, about half of *An Essay on the Principle of Population* is dedicated to a vigorous refutation of many of the Age of Enlightenment principles espoused by the Marquis de Condorcet and other Enlightenment figures (Malthus 1798). On the other hand, the 1960′s were a decade of unbridled confidence in science and technology, with the increased use of agricultural technologies such as the Haber–Bosch method for nitrogen fixation (Hirsch and Mauchline 2015), organophosphate pesticides (Aktar et al. 2009), farm mechanization, motorized transport of perishable produce with the rail and road infrastructure to support it, or genetic breeding technologies (Pingali 2012), in addition to nuclear power, manned space exploration, and the early stages of computing machines. Despite the ongoing Cold War, political instability in much of the Southern Hemisphere, and major famines (Max Roser (2016)—‘Famines’. Published online at OurWorldInData.org. Retrieved from: https://ourworldindata.org/famines/ [Online Resource]), the early 60s were also a time of economic expansion, development of antibiotics and vaccines, and large hydroelectric/irrigation and transport infrastructure projects. It is thus understandable that Malthus would have been pessimistic, and Boserup would have been optimistic about the future given these very different historical contexts.

What Happens When an Insufficient Model is Adopted as a Guide for Programmatic Decisions

Unfortunately, ideological migration into either the Malthusian or Boserupian camps holds the danger that development decisions are based on one of two outdated and limited views of development and human progress, or worse yet, decisions based on a poor understanding of the assumptions and limits of either camp. Those inclined to the Neo-Malthusian view will tend to view any population growth beyond a certain (and undefined) level as a hazard, and therefore place population control at the top of their long-term agenda, followed closely by conservation of natural resources. Population pessimists can point to a long list of examples of environmental degradation, disease, famines, and resource wars to support their case. Those tending to the Boserupian view choose to place their faith in technological innovation to overcome the problems associated with dense and growing populations. Population optimists can point to a long history of innovation and a global population far larger than what could reasonably have been imagined in Mathus' or even Boserup's time.

Examples of a poor understanding of either view are clearly evident in the scientific and popular literature, as well in the goals of charitable foundations. An article in the December 2015 *Nature* under the title of '*Nature* Myths' [Myth 5: The human population is growing exponentially (and we're doomed)], in a bizarre juxtaposition of Malthusian and Boserupian views, the author claimed that overpopulation is a myth because, 'The world's population…has enough to eat… Yet hunger and malnutrition persist worldwide. This is because about 55% of the food grown is divided between feeding cattle, making fuel and other materials or going to waste… And what remains is not evenly distributed—the rich have plenty, the poor have little. Likewise, water is not scarce on a global scale, even though 1.2 billion people live in areas where it is.' (Scudellari 2015). By implication the author suggests that the solution to hunger and malnutrition is to evenly distribute what is produced, reduce the percentage of what is fed to cattle or other non-food uses, and reduce waste. What is not stated is why things are the way they are, how they got that way, nor what would be the result of these solutions, likely because of confusion over whether population is the problem or the solution.

Similarly, but not as egregiously, the Bill and Melinda Gates Foundation outlines its strategy for agricultural development using a Malthusian assessment with an additional view that some forms of technological interventions have been counterproductive (http://www.gatesfoundation.org/What-We-Do/Global-Development/Agricultural-Development).

> 'From the 1960s to 1980s, the "Green Revolution"…helped to double food production and saved hundreds of millions of lives…This was not the case in Sub-Saharan Africa, however, where some Green Revolution approaches were tried but failed. Meanwhile, in the intervening years, *population growth, rising incomes, dwindling natural resources, and a changing climate have caused food prices to rise and agricultural productivity has once again become strained* [emphasis added]. Three-quarters of the world's poorest people get

their food and income by farming small plots of land about the size of a football field. Most of them barely get by—struggling with unproductive soil, plant diseases, pests, and drought. Their livestock are frequently weak or sick. Reliable markets for their products and good information about pricing are hard to come by, and government policies rarely serve their interests well. These factors, in turn, put millions of families at risk for poverty and hunger as well as malnutrition—the world's most serious health problem and the single biggest contributor to child mortality. At the same time, one consequence of the first Green Revolution—excessive fertilizer use leading to water pollution—underscores the importance of sustainability to safeguard both environmental and human health.'

The Gates Foundation response to the Malthusian model is a strictly Boserupian goal, 'to reduce hunger and poverty for millions of farming families in Sub-Saharan Africa and South Asia by increasing agricultural productivity in a sustainable way.' One cannot fail to note that there is no part of their goal that seeks to harmonize population with what can sustainably be produced, or with the increasingly critical shortage of water.

The United Nations depends largely on a Boserupian economic development model in its Sustainable Development Goals for 2030. Their Goal 2 is to, 'End hunger, achieve food security and improved nutrition and promote sustainable agriculture' (http://www.undp.org/content/undp/en/home/sdgoverview/post-2015-development-agenda/goal-2.html). In a recent report, the UN Development Programme claims, 'Rapid economic growth and increased agricultural productivity over the past two decades has seen the proportion of undernourished people drop by almost half. Many developing countries that used to suffer from famine and hunger can now meet the nutritional needs of the most vulnerable… Unfortunately, extreme hunger and malnutrition remain a huge barrier to development in many countries. 795 million people are estimated to be chronically undernourished as of 2014, often as a direct consequence of environmental degradation, drought and loss of biodiversity.' The latter statement indicates that the Malthus model is still applicable and recognized as causative, but the UN promotion of sustainable agricultural practices to improve 'the livelihoods and capacities of small scale famers, allowing equal access to land, technology and markets' reflects confidence in technology and social organization, a distinctly Boserupian solution.

Mixing these models without consideration of current environmental, political and technological parameters does not make sense. For example, a Malthusian analysis of the problem in a certain developing region might state that there is not enough production of local food to sustain the current population because all of the available arable land is being intensively cultivated, and there is no capital available for importation of additional food, therefore children are chronically undernourished, which increases the incidence and severity of an endemic infectious disease. The Boserupian model stipulates that to increase food production there needs to be an increase in population or in the concentration of population, and land use can be intensified. This model does not take into consideration limits in intensification of land use, nor what the upper limits of population are. Therefore this development solution is absurd, as it is clear that the proposed solution would only exacerbate the region's endemic problems. Despite the evident weaknesses of a mixed development model, each of the cited examples of development goals and plans applies this mixed model to some degree.

Formation of a New Agricultural Development Model

Any model is subject to certain conceptual premises that define its limitations. Models are a representation, usually in mathematical terms, of the behavior of real systems, objects, or devices. There are three main reasons for constructing a model, which is as true for an agricultural development model as any other. A well-constructed model gives insight into the mechanisms of a system and how they interact. Because of this, a model needs to be explicit in both its purpose and scope. There are many possible levels of abstraction, or complexity, for any given model, and the level of detail depends on its intended use. Boserup's (1965) interpretation of her observations of agrarian change resulting in differences in land use as a result of population fluctuation can be modeled very simply by a sigmoidal curve (Fig. 1). Using this simple logistic function model, increases in population density result in the necessity to intensify agriculture by reducing, and eventually eliminating fallow periods, by the introduction of animal labor, and eventually by multicropping. At some point little more intensification is possible, represented by the asymptote at y_{max}. This can also be expressed as $y = \frac{y_{max}}{1+e^{-k(x-x_0)}}$, where e is the natural log, x_0 is the x value of the sigmoidal midpoint, y_{max} is the curve maximum value, and k is the steepness of the curve. (Coincidentally, and perhaps ironically, this function was devised by Belgian mathematician Pierre Francois Verhulst after reading Malthus' *Essay on the Principle of Population* as a mathematical model to describe the limits of population expansion.) Additional parameters can be added to the simple model to account for other phenomena in the system (Fig. 2). This type of model can be used to define what features of the variables within the model are determined by the parameters chosen (deterministic model). Deterministic models can be used to find out if our current understanding is sufficient to explain the behavior of a system, and can be used to help explain events or processes that have occurred in the past. However, a deterministic model is very sensitive to the quality of the data, and thus the ability to measure its parameters. This is often a difficult problem when the historical record is incomplete, or where the data are unreliable because of small sample size, anecdotal, or which qualify only if a number of assumptions are accepted. If a deterministic model can be validated by changing scales or tested under different conditions using real data, it may be used for extrapolation or prediction. Neither the Neo-Malthusian nor Boserupian models have been sufficiently validated, likely because of their technical limitations, the lack of adequate data, and problems with scalability.

Any new development model would begin by identifying the limiting environmental (i.e. non-human) factors, and incorporate limitations and regulating conditions for each factor. Because human capital is also important, demographics as constrained by political, economic and social factors would also have to be

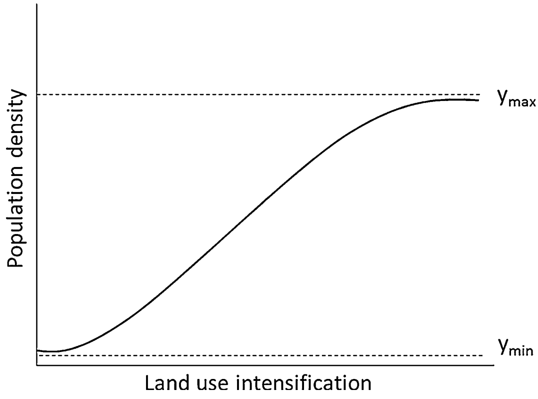

Fig. 1 Simple interpretation of Boserup's (1965) model of land use modification in response to population density. As a population increases, long-fallow agriculture is replaced by short-fallow, and finally by intensive, year-round agriculture. At some point (y_{max}), intensification within a given land area reaches a maximum

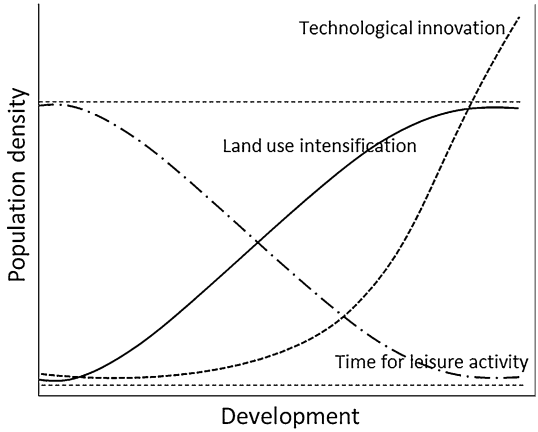

Fig. 2 Additional elements of the 1965 Boserup agricultural development model, with decrease in the time for leisure activity and population-dependent technological innovation

considered. Even the relatively simple parameters shown in Fig. 2 would be difficult to define and validate, making a comprehensive global model an extremely difficult proposition.

Conclusions

Population and agricultural development policy decisions have been guided for over 200 years by a narrow set of circumstances and assumptions, challenged 50 years ago by another set of assumptions, but both have been eclipsed by challenges that could not been foreseen by either Boserup or Malthus. A new model must be applied to agricultural development based on the clearly daunting challenges presented by environmental limits and population growth, if a rational approach to policy is to be expected. Because development agencies, foundations, and governments make critical decisions about resource allocation and policies based not only on empirical evidence, but also on a priori assumptions associated with some overarching concept of how agricultural development works, it is crucial that whatever new type of model is developed would account for the current demographic, environmental, and geopolitical context. It is also important that governmental and non-governmental organizations recognize the assumptions associated with their interpretation of empirical data, which are likely Neo-Malthusian, Boserupian, or perhaps some amalgam of the two. Some would argue that the disparity between the principles and models of Malthus and Boserup is a false dichotomy. However, a mixed model *per se* doesn't work because the two are based on very different assumptions. Boserup's model of production as the dependent variable with population growth as the independent variable makes the assumption that both are subject to elasticity, and in the late 1950's and early 1960's, although there were already indications of serious problems with this assumption, this may have been a reasonable assumption. Malthusian models are premised on the inelasticity of land use at a given time, and essentially zero-sum economics. Immigration allows population some degree of elasticity. Even though diffusion of technology, mobilization of energy and other resources, and social development may all be elastic, soil erosion, climate change, and the availability of water are apparently not (Jaramillo and Destouni 2015; Josephson et al. 2014; Laney 2002; Mekonnen and Hoekstra 2016; Pender 1998; Steffen et al. 2015; Turner and Ali 1996).

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Compliance with Ethical Standards

Conflict of interest There are no known conflicts of interest on the part of the author or host institution associated with the preparation of this manuscript.

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