



Performing an Invisibility Spell: Global Models, Food Regimes and Smallholders

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[Paper first received, 4 November 2015; in final form, 16 May 2016]

Abstract. The present construction of global representations of food and farming is problematic. For example, how can we ‘know’ the world needs to double food production even though we cannot foresee a food crisis? How can we estimate investment opportunities while failing to quantify their impacts on smallholders? Global models constrain the manner in which we perceive the food regime while producing such representations. We need to identify the causal relations embedded inside models’ equations and why they are arrayed in this fashion. This article combines actor-network theory and structuration theory to analyse a sample of 70 global models. It locates the modules and equations of these black boxes in the sociotechnical and political context of their production. Finally, a bibliometric analysis sketches the overall epistemic community that drove models into success or extinction. Dominant global models recycle equations, modules and databases to effectuate narrow worlds. They make smallholder farming invisible in spite of its prevalence around the world. They do not address food needs and construct pixellated representations of underutilized land. They systematically favour large-scale agricultural trade and investments in production and productivity. This reflects the structure of signification modellers adhere to as well as the structure of domination they are embedded in. Securing clients ensures the success of global models independently from their validation. The article demonstrates the manner in which modelling is a social practice embedded in power relations. Considering simultaneously the structure of domination formalized inside models and surrounding modelling is crucial. Future research should investigate how various actors resort to global models to champion their goals. It should question the policy recommendations drawn from such models and their relevance as decision support tools.

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Introduction

A food regime is defined as a structure of production and consumption of food on a world scale, including the explicit and implicit rules that govern it (Friedmann, 1993). As such, a food regime is a structure of domination, according to the idiom of structuration theory (Jabri, 1996). Global models aim to represent food production and consumption around the world. They play a pivotal role in the construction of specific patterns of production and consumption, a role which goes far beyond representing these patterns. Which actors want these models, for which purposes, and how they use them needs to be examined at the same time as we study the manner these models attempt to represent the world. The 'co-production' of scientific knowledge designates the process whereby the latter both embeds and is embedded in social identities, institutions, representations and discourses (Jasanoff, 2004). This article investigates the co-production of global models and the food regimes as well as some of the consequences of this co-production.

Science is a social practice. The multiplicity of knowledge productions concerning the environment or agriculture makes the practice of environmental science and the study of food production and consumption even more complex than that of classic laboratory fields. Scientists are unavoidably influenced by the perceived needs of those who try to 'apply' environmental knowledge. They are also influenced by the widely circulating knowledge claims made by scientists and others within and outside their fields. As a result, scientific practice cannot be understood in isolation from the processes of knowledge circulation and application (Turner, 2011).

Actor-network theory (ANT) has argued against defining a priori the context within which actors interact. It has distinguished entities and actors on the basis of their connections with other entities and other actors (Latour, 2007). This has proved immensely useful to study the role of agency, whether human or non-human. Its unfortunate side effect, however, is to neglect power interactions among various actors. If interactions are not examined within their wider context, the power imbalances within which actors evolve can go unnoticed. We risk ascribing an agency to people acting under duress, for example. Structuration theory reconciles the consideration of human agency with the consideration of structures of domination within society (Jabri, 1996, 2013). Both agency and structure need to be examined when we turn to human interactions with the environment such as occurs in agriculture (Trottier, 2007). Harnessing this approach allows us to shed new light on the manner in which global models contribute to the global food regime.

The term 'black box' designates a scientific claim once it has been turned into an unquestionable scientific fact, or a machine after it has been made to work (Latour, 1987). This article opens 70 'black boxes' as it analyses a sample of global models and examines the causal relations that are put into equations inside them. It locates these causal relations in the context within which the models were produced. It questions the silences within these models. It shows the specific worlds that such models produce as well as the policy recommendations they can or cannot lead to. It questions the types of government embedded in such models. The article then examines the links among the numerous models that often borrow modules or equations from one another. This sheds light on the struggles or extinction of alternative models. Finally, the article turns to the epistemic communities that have championed various models. The article argues that the co-production of global models and the food regime means that models effectuate the world far more than they represent it.

Understanding the causal relations embedded within global models of food pro-

duction and consumption allows us to identify which agency can actually be exerted according to these models. It also allows us to identify which actors are effectively silenced because their agency cannot be represented by these models. Our study demonstrates that the models who became dominant were the ones who enrolled most allies, exactly as ANT expects. It also demonstrates that those models that succeeded in enrolling most actors were embedding specific power interactions within their equations. They contributed to constructing a structure of signification that suited a specific structure of domination, exactly as structuration theory expects. Successful global models thus posited, the only possible development of the food regime occurs through international trade and through targeted investments, for example on the basis of potential yields.

Beyond shedding light on the manner in which models contribute to the food regime, this article shows the usefulness of combining ANT and structuration theory. These two approaches have tended to shun each other when tackling such complexity.

Global Models: Opening the Black Box

What Is Inside a Model?

For the purposes of this article, a model is understood strictly as a set of computerized, mathematical relations that link variables within functions purporting to explain, describe, judge or predict. The article examines models that deal with food consumption and production at the global scale. Each model puts forward a number of causal relations linking variables such as economic demand, agronomic practices, climatic conditions, and population growth, to represent the global picture. The manner in which these causal relations are formulated and arrayed is shaped by the structure of signification the modellers favour. Structuration theory defines a structure of signification as the overall production of meaning achieved by the creation and repeated use of interpretive schemes to describe the world and our actions within it (Jabri, 1996). A structure of signification emphasizing interactions among states produces a world-scale depiction of the food regime. A structure of signification emphasizing interactions, such as climate change, among a much greater variety of actors around the world produces a global-scale depiction of the food regime. Which variables modellers choose to integrate and how they arrange them into causal relations allows us to distinguish four main categories of models: economic models, biophysical models, integrated models and hybrid models, as illustrated in Table 1.

Our sample of 70 global models was built through a literature review of large-scale modelling of food and farming, including grey literature on the different modelling enterprises. We applied a broad sampling method taking into account both academic models and those developed by think tanks, international institutions and ministries. The purpose of this sample is to characterize the practice of global modelling rather than to identify the 'representative' models (Becker, 1997). Out of an initial set of 90 models, 20 were discarded because of lack of information, limited focus on food and farming issues, or limited spatial scale. Early warning systems of food and farming and monitoring of food insecurity were also excluded because they do not offer a formalization of food and farming systems but rather a collection of indicators. Such representations were not considered as global models for the purpose of our exercise.

Global economic models focus on the exchanges of agricultural products. They relied initially on a set of national modules, usually those of main exporting or importing states such as the United States, Canada or Australia, and an additional module describing the 'rest of the world'. Such modules are connected through international market functions where demand and supply meet and thus determine physical and economic equilibrium prices. Economic models thus rely on pre-existing national-scale models and databases. By the 1970s, time series-oriented models had started harnessing the latter to extrapolate past trends in order to predict future trends. Later, models based on a general equilibrium theory, relying on price to balance demand and supply supplanted them.

Global biophysical models focus on the production potential of the planet from an agronomic point of view. Their equations link physical variables such as rainfall, temperature, and surface properties to calculate the quantity of biomass that can be

Table 1. Typology of global models.

Type of Model	Representation embedded in model	Subcategory	Representation of food and farming	Heyday	Users
Economic	Agricultural sector -> supply	Time series	Statistics of past trends -> future trends	1970s	FAO, World Bank, USDA
	Food -> demand	Equilibrium	Prices balance demand and supply	late 1970s	World Bank, USDA, OECD, IFPRI
Biophysical	Potential agricultural production of planet and impact of environmental or technical alternatives	Theory based	Yield according to agronomic theory	late 1970s	Wageningen University, IIASA, INRA, CIRAD
		Data driven	Yield as a function of statistical production data	1990s	Stanford University, Goddard Institute for Space Studies (Columbia University)
Integrated	Interactions of human activities and the environment, incl. agricultural production and consumption	Homogeneous systems dynamics	Interactions and retroactions between variables	1970s	MIT, Club of Rome, Bariloche Foundation
		Heterogeneous models	Yield according to agronomic theory, prices according to equilibrium theory	1990s	PBL Netherlands Environmental Assessment Agency, Centre for Global Modelling (Japan), United Nations Trade and Development
Hybrid	Link global datasets of production and socioeconomic data at a pixel scale		Cross data layers such as economic indicators, food consumption, agricultural production and distances to roads	2000s	Center for Sustainability and the Global Environment (University of Wisconsin-Madison), Institute on the Environment (University of Minnesota)

produced. They can be theory based and determine the yield strictly on the basis of agronomic theory, or data driven. In this case, they rely on the statistical analysis of datasets to identify the main contributions to the crop yields. Databases the Food and Agricultural Organization of the United Nations (FAO) collected across countries served to elaborate the first biophysical models. Later, the ecophysiological measurements carried out in experimental stations around the planet and remote-sensing data fed them further.

Global integrated models focus on the interactions between human activities, as economic models do, and the environment, as biophysical models do. Two main sorts of integrated models have emerged. Homogeneous models have been developed, each by a single team, often using system dynamics modeling. These have tended not to include prices, favouring kilocalories instead, for example. They have also tended to extinction. Heterogeneous models have been developed by several teams, each contributing its own module to the overall model. They link modules from each of the economic and biophysical models, gathering variables that are measured in different units, such as kilocalories, dollars or cubic meters. These have tended to include prices. And they have fared much better than homogeneous models.

Global hybrid models overlap broad sets of factors, whether economic, physical or social, as layers of pixels. Most land-use datasets integrated in global models have a 5-arc minute resolution, in other words the pixels represent around 100 km² or 10000 ha. Hybrid models use the pixel as the basic unit of analysis instead of the state. Yet the state often remains the central unit of data gathering even within global datasets. The representations that emerge from these models thus sometimes express divisions along national borders even when this was not intended.

Locating the Causal Relations Embedded in the Models

Locating the causal relations embedded in each category of models in the political and economic context within which the models emerged is important. It sheds much light on why these causal relations were put forward. Once it is enshrined inside an equation within a model, a causal relation becomes essentialized, i.e. the fact that it is a socially constructed depiction of reality no longer appears. Instead, this causal relation appears as a 'law of nature'. Locating the construction of the models, together with the specific causal relations they embed, allows a more critical understanding of the role models play in the co-production of the food regime.

National research institutions and national planning agencies were at the forefront of the development of economic models. The Ministry of Agriculture Forestry and Fisheries in Japan produced the World Basic Food Model in 1974 and later IFP-SIM.¹ The United States Department of Agriculture (USDA) developed the World Grain-Oilseed-Livestock Economy model (GOL) and SWOPSIM in the 1970s. The Institut national de la recherche agronomique (INRA), in France, developed MISS. Such models emerged then because datasets and adequate computing facilities became available. Researchers and planners turned to datasets produced by national accounting systems, concerning exports, imports, inputs and outputs, as well as to datasets concerning elasticities (Josling et al., 2010). Most industrialized, capitalist states set up such datasets in the 1950s to inform national policy. This was a state-driven process where economists and civil servants defined categories to analyse and manage the economy. Keynesianism dominated at that time, and both econo-

mists and civil servants usually considered the state was in charge of regulating economic markets (Desrosières, 2003).

The development of global economic models occurred at a time when controversy raged concerning national agricultural subsidies and the liberalization of international agricultural trade. Several Western countries were producing more than they could consume and favoured liberalization of international exchanges. American economists perceived models as a pragmatic tool to guide policies (De Benedictis et al. 1991; Armatte, 2010). As the development of the categories and of the datasets was only carried out in Northern states, it fitted their economic structure, where agriculture is industrialized and food commercialized. This left the rest of the world in a void, both from the point of view of data and the development of appropriate categories to describe widespread activities, such as smallholder agriculture. However, the dominant ideology, soon after the Second World War, promoted a technological solution to the food problem, one where agricultural technology and increased production should end hunger (Cornilleau and Joly, 2014). Information concerning smallholder agriculture seemed unimportant because, as a relic of the past, it would soon be transformed into more efficient, scientifically driven systems.

As opposed to economic models, which were state driven, global biophysical models were driven by international initiatives. Spurred by the 1972 *Limits to Growth* report, international organizations sought to establish the carrying capacity of the planet. They urged scientists to turn away from national food self-sufficiency and to think globally. Wageningen University developed MOIRA in 1972 and the International Institute of Applied Systems Analysis (IIASA) produced the most detailed biophysical model, the Global Agro Ecological Zones project. FAO collected worldwide datasets, establishing the first satellite databases to map cultivated areas around the world. In the 1970s, the carrying capacity was believed to be determined strictly by physical and technical constraints. Environmental research later demonstrated that the carrying capacity of any ecosystem is also a function of human practices. Biophysical models predated that understanding and the causal relations they embed reflect this.

The rise of system dynamics and the cold war both fostered the rise of global integrated models. Protecting the global environment could rally both East and West around a common goal, thereby appeasing tensions. Global modeling was appealing because this representation of the world dis-embeds production and consumption data from their local political context and thus appears apolitical. The causal relations it embeds in its equations are deeply political, but the overall tool appears to be neutral and technical (Taylor and Buttel, 1992). The IIASA was thus located in Vienna, aiming to gather scientists from communist and capitalist states, seeking to respond to the *Limits to Growth* report with the development of new models.

Global hybrid models proliferated especially after 2000. This was a time when satellite-produced datasets became easily available for all, as well as Geographic Information Systems (GIS). Financial deregulation and new doctrines promoting intervention inside state affairs withered away the Westphalian structure of the international community. The state ceased to appear as the basic building block and the only legitimate actor. Hybrid models such as the food density map of the FAO (Matuschke, 2009) reflected this change as they replaced a world composed of a collection of states with a world composed of a collection of pixels.

In recent years, all four types of models underwent a 'spatial turn', i.e. they integrated GIS and undertook to project their results on grids of pixels. This approach

was championed by the World Bank Development Report in 2009, which insisted on economic geography. This systematic spatialization has several consequences. It projects homogeneity on any area represented by one pixel, thereby erasing anything that exists only at a smaller scale. The grid size becomes extremely important in making small-scale farming systems invisible or not (Trottier, 2006; Chouquer, 2012).

As we located the production of models within their political and economic contexts, it is worth also locating the extinction of some models. Economic models based on statistical series fell into disuse because they could not model prices and simulate market dynamics. World Bank economists judged them inferior because they considered the market was central to the world food system and food security. Models, for example LAWM, which included radical changes such as land redistribution scenarios, were deemed unrealistic and later fell into oblivion (Bernardini, 1974). Actually, any model that could not target and secure the loyalty of clients was doomed. Siegmann noted that finding clients for a model was very problematic unless it catered specifically to their practical concerns, such as economic forecasts (Siegmann, 1985).

Which Silences within These Models?

Any scientific discourse is based on the silence of its object (Foucault, 1972). Ignorance is part of the construction of science, either as a driver or as a product (Proctor, 2008). Scientific practice, by selecting information, highlighting pathways or stabilizing methods, can produce numerous silences, inadvertently or deliberately. All four categories of models embed important silences. We will mention only three, which have far reaching consequences: silence on the context of the data, silence on non-monetary exchanges, and silences on food needs.

All data used in these models are necessarily dis-embedded from its context. Agricultural systems appear as starting points and evolve only under the pressure of variables such as prices, technological features and trade policies. As a consequence all previous subsidies and state support that shaped these production systems are essentialized, i.e. they are made to appear as a part of nature. In these models, a Californian agribusiness heir to decades of free water channelled thanks to infrastructure funded by the American taxpayer is indistinguishable from a Malian farm practicing subsistence agriculture. The essentialization of socially constructed phenomena prevents models from integrating their evolution.

These models use databases structured according to categories that were defined to address agricultural marketing in the 1950s or 1970s. Thus, food production and consumption that is not based on monetary exchanges does not exist within the representation produced by these models. The term *family farming* designates a form of organization of agricultural production 'characterised by organic links between the family and the production unit and by the mobilisation of family labour, excluding permanent employees' (Bélières et al., 2015, p. 20). Quantifying family farming and on-farm consumption is notoriously difficult. However, statistics from 81 countries, gathering 84% of the world population, show that 85% of agricultural holdings, i.e. 373 million holdings, are family farms under 2 ha (Bélières et al., 2015; Sourisseau, 2015). This is far smaller than the usual grid size used by global models, around 10000 ha. Undeniably, the bulk of basic food production in these countries originates from family farms, with important on-farm consumption and contribution to the

livelihoods of extended families. Models are particularly ill equipped to represent the contribution of family farming.

Finally, the manner in which the modellers pictured the food regime shaped the equations within the models. These usually rely on food prices as a proxy to food access. Drawing on the datasets produced by national accounting systems, they calculate the point at which demand meets supply. Food demand is a function representing the amount of food an individual wishes to buy at a given price. The demand expressed by someone who has no money at all is necessarily satisfied, even when he is starving to death. The demand expressed by an individual matches his needs only if the market prices for satisfying them are affordable for that person. Food needs include both a quantitative dimension, as individuals require a minimum number of calories, and a qualitative dimension. Indeed, individuals require a variety of foods to avoid malnutrition and to maintain the cultural processes in which food is embedded. Dominant models make needs invisible because they only focus on demand. Obesity is also made invisible, because the causal relations framed within the models do not allow to represent it either. Yet, obesity is a major problem within the food regime. Models most widely used are therefore structurally incapable of addressing food needs.

In short, the silences within these models are important and are part of their structure. They contribute to representing a specific food regime. Many other silences could be identified. For example, cattle raising is often under-represented, especially extensive pastoralism, because the land used for this activity is difficult to represent. Access to infrastructure necessary for distribution and exchange capacity is rarely represented within these models.

Which Worlds Do These Models Produce?

All four categories of global models construct a very specific paradigm to understand a food regime, thereby portraying very few options for its development. They contribute to the co-production of narrow worlds.

Global economic and integrated models rely on a world structured into states, which they reproduce within the representations they generate. Hybrid and biophysical models rely on sets of pixels that do not show state borders. Thus, hybrid and biophysical models represent Europe as a global wheat basket whereas economic models represent it as a collection of states or economic regions producing and trading wheat. None of them represent the trade of crops within states from one region able to produce it to another unable to produce it, such as the trade of olives between the south and the north of France, for example.

Global economic models and modules place states and exchanges among states at the centre of the world they produce. For example, the Basic Linked System (BLS) model, links national markets to a world market (Fischer and Frohberg, 1982). Through iterations, they balance national demands and supplies showing different elasticities. Unavoidably, this iteration process concludes that countries with a lower marginal cost of production will specialize in this production. Development can only mean a greater international food trade. Yet, currently, international food trade represents only a small fraction of food production. Less than 15% of cereals produced in the world are currently exchanged on world food markets, for example (FAO, 2015). These models thus *effectuate* a world where international food trade is the dominant development path in spite of the fact that it remains marginal.

Biophysical and hybrid models produce sets of pixels, each of which is independent from the other. They co-produce a world where intervention is possible over various spaces without any need for these spaces to match the boundaries of a state. For example, global datasets allow identifying ‘climate risk hot spots’ where climate change is most likely to impact agricultural yields negatively (Deryng et al., 2011). Adaptation strategies, such as planting new crops, for example, can then target specific zones that might straddle a national border or be a small subset of a larger national space (Lobell et al., 2008). These models thus *effectuate* a world where state sovereignty does not matter much.

The spatial turn, which most models underwent after the 2000s, has had an especially far-reaching consequence. Projecting datasets on grids of pixels has produced underutilized lands and vacant lands. Dominant models do not include land uses such as pastoralism or non-monetarized agriculture in their inputs or their outputs. The homogeneity projected on each pixel, usually representing 10 000 ha, masks a great diversity of resource access and property regimes. Fine-grain representations can show clusters of farms smaller than 10 ha, but, for several reasons, such representations are not integrated in global models. First of all, high resolution datasets exist concerning some regions of the world, such as Europe, but not the entire world. As a result, their integration in a global model is problematic. Moreover, they require prohibitive processing capacities. Mixed pixels allow considering several land uses within an area smaller than that represented by the pixel. However, neither agronomy, economic or ecological theory is yet capable of integrating this category of ‘mixed pixel’ within the calculations carried out by the models. As a result, those smallholders who are active over a scalar level smaller than that represented by a pixel are made invisible. Vacant land is thus constructed within a representation that shows intervention on any portion of space as possible or even desirable.

Finally, these models have very poor representation of transport infrastructure, which is crucial for the exchange of agricultural products. The world they construct is one where transport is not problematic, where the trade-offs between transport infrastructure and other land uses, whether agricultural or environmental, are negligible.

In summary, all four categories of models produce simplified worlds where few interventions are possible and only partially assessed. In global economic models and integrated models centred on equilibrium theory, the only possible development of the food regime involves monetarized agricultural production and international trade. In global biophysical models and hybrid models, vacant yet potentially productive land replaces large stretches of smallholder agriculture and pastoralism. They produce worlds where intervention can be elaborated on portions of space anywhere on the planet. Therefore, the policy recommendations they can lead to are worth examining to understand the role they play in the construction of the food regime.

How Global Models Constrain the Scope of Potential Policy Recommendations

The mechanisms whereby models function restrict greatly the sort of policy recommendations they can lead to. They are unable, structurally, to inform policy that would include smallholder agriculture because the categories they rely on under-represent it. However, since the 2000s their pixelated design allows them to promote investments in any area on the basis of its biophysical and economic potential, re-

ardless of its political or social context. The contract 'Lessons for the Large-scale Acquisition of Land from a Global Analysis of Agricultural Land Use' between the IIASA and the World Bank illustrates this. It produced tables of results expressed as potentially available good quality land rated according to its accessibility, defined as reachable within six hours of road travel, and its population density (Fischer and Shah, 2010). This report assessed, in dollars, the profitability of investments by calculating the ratio of potential production over present production.

The causal relations embedded in models lead them to recommend policies that sometimes satisfy demand but never address food needs. Economic models seek to balance demand and supply. They do not seek to end hunger. They cannot recommend policy targeting the poor, whose demand is automatically satisfied because they don't have money to spend on food. Hybrid models produce policy recommendations where the aim of food policies is transformed from an effectivity principle, such as ending hunger, to an efficiency strategy, such as maximizing profitability of investment. These models are useful to produce policy recommendations to support investors. They cannot possibly contribute to policy recommendations to support livelihoods they make invisible.

The manner in which malnutrition has been embedded in models' equations locks them into productivist policy recommendations, whereby the quantity of food produced should be increased in order to decrease malnutrition. Yet, malnutrition and famine systematically result from access problems, often in situations where production is unproblematic (Sen, 1981). The International Food Policy Research Institute (IFPRI) developed a partial equilibrium model, IMPACT, in 1995, to promote investment in agricultural research. IMPACT calculates the production of a foodstuff so as to equilibrate food demand, a curve determined by consumer prices, per capita income and elasticities, instead of by the population's needs. The model thus mechanically produces greater food demand where revenues grow and undernutrition where they are weak. This partial equilibrium model uses two indicators to represent hunger: food availability and child malnutrition. Food availability is expressed in terms of quantity of food per person as kg or calories per day. Child malnutrition is expressed in terms of the percentage of children between zero and five years of age whose weight was under two standard deviations in comparison with the standards of the World Health Organization. This is illustrated by the following formula (Rosegrant and IMPACT Development Team, 2012, p. 28).

$$\Delta_{t,2000} \text{MAL} = -25.24 \times \ln \left[\frac{\text{KCAL}_t}{\text{KCAL}_{2000}} \right] - 71.76 \times \Delta_{t,2000} \text{LFEXPRAT} \\ - 0.22 \times \Delta_{t,2000} \text{SCH} - 0.08 \times \Delta_{t,2000} \text{WATER}$$

where MAL = percentage of malnourished children; KCAL = per capita kilocaloric availability; LFEXPRAT = ratio of female to male life expectancy at birth; SCH = total female enrolment in secondary education (any age group) as a percentage of the female age group (corresponding to national regulations for secondary education); WATER = percentage of population with access to safe water; $\Delta_{t,2000}$ = the difference between the variable values at time t and the base year 2000.

Based on this percentage, the number of malnourished children may be calculated by multiplying MAL by the number of children between 0 and 5 years old in the population. All variables are exogenous, except KCAL. 80% of KCAL is based on the variable 'Total Supply' (Production + Imports - Exports - Other Uses) calculated by the model. The other 20% (corresponding to the contribution of sugar, vegetable, fish and fruits) is based on FAO studies.

The structure of the model links child malnutrition to a single endogenous variable: food availability. The other variables in the equation are exogenous, in other words, these values are fed as entry data into the model. As a result, hunger cannot be reduced in the model unless food availability, understood here as meaning production, is increased. Therefore IMPACT automatically leads to a policy recommendation of increasing food production.

Simultaneously, IMPACT produces vacant lands. Its representation of food production is based on national and subnational agricultural statistics merged with remote sensed cropland data. (Robinson et al., 2015) Both are inadequate to grasp small scale farming. IMPACT also fails to take into account on-farm consumption and the livelihoods of the rural population. Therefore, the model inevitably leads to the representation of underproductive land. It simultaneously promotes policy recommendations according to which investments should be made in agriculture to satisfy an ever increasing food demand. Therefore it promotes land uses competing with the ones actually in place, all in the name of ending hunger, which it doesn't address. The second part of this article will return to IMPACT, showing that this equation to represent malnutrition was carried over into several subsequent models.

Which Types of Government Do These Models Embed?

Global models play a crucial role in the government of the food regime. The term *governmentality* was coined to describe a type of political rationality whereby technology and knowledge are deployed to organize human populations in order to steer them into a certain type of behaviour (Foucault, 2007). Global models participate in a governmentality that has global ramifications, whether intended or not.

The first economic models were produced at a time when the United States sought to reroute the surplus it produced towards developing countries through food aid. America thus sought to ward off communism and promote national models of agro-industrialization as a path to development in poor countries (McMichael, 2009). Global models that found clients in the 1970s shared this vision of the food regime. They focused on international markets, technologies, free trade and national growth. They embedded the mechanisms their clients wanted to put in place.

Are global models now embedding a new food regime? As they have switched from state to pixel as their basic unit since the spatial turn, they are compatible with the corporate food regime McMichael (2009) argues has now arisen. The latter is based on free trade rules, the persistence of subsidies in Northern countries and decreased agricultural regulations in Southern countries. It operates through the corporatization of agriculture, the appropriation of land for agro-exporting, and the displacement of smallholders to a pool of impoverished labour. Global representations identifying fertile spaces to invest and urban populations to feed effectuate this food regime.

So, what is inside a model? After opening the black box and locating the causal relations embedded in their equations as well as their silences, we conclude that they are both products of science and producers of the food regime. A food regime is a political structure, a political project. This political project lies inside the models, structuring the causal relations they embed in their equations. In the co-productionist idiom this is typical of scientific discourses, which systematically embody both what the world is and what it ought to be (Jasanoff, 2005). The important point here is that the models that fared well, those that didn't drift into extinction, embody a food

regime that relies on international exchanges of foodstuff, where subsistence agriculture doesn't exist, where only demand matters, instead of needs, and where the only path forward lies in investments in agricultural production and productivity. Such models construct a world that welcomes what is often described as land grabs.

Do Models Breed?

Anyone wishing to represent world food production and consumption can pick among a vast number of global models. However, this does not mean a similarly high number of independent assessments.

Proliferation and Reproduction

Models are rarely constructed independently from other models. They are based on similar equations and thus rely on similar hypotheses. Dominant global economic models are based on equilibrium theory. They incorporate little real-time data and simulate poorly the vulnerability of households to price shocks. As a result, none of them can either analyse or predict a food crisis, such as occurred in 2008 (Headey, 2011). Global biophysical models are based on independent pixels, each of which is supposed to be optimized. They all tend to promote crops according to the biophysical potentiality of the land within each of these pixels, without consideration for the knowledge and experience local farmers might or might not have. Conversely, these models do not include retro-actions of large scale monocropping, such as vulnerability to pests or the dependency on the price of the crop.

Global models share the same datasets. The Global Trade Analysis Project (GTAP) database, which contains bilateral trade information, transport and protection linkages, is used by thousands of economic modelers around the world. Most models also use FAO datasets for food production and consumption. This restricts the possibility of assessing the quality of the datasets and other parameters as they outnumber greatly the independent observations that are available. The hegemonic position of a few institutions and databases thus leads global models and their results to be used in spite of the impossibility to validate them.

More crucially, the modules of one global model are often recycled from one model to another. It seems models can breed and produce several generations of offspring, each new model carrying the same equations as the previous generation in the manner in which living organisms carry DNA. Some modellers like to refer to the need to 'have models marry other models' (Cornilleau, forthcoming). The IMPACT model's family tree illustrates this quite well. Produced by the think tank IFPRI in the 1990s, it was reused in 2002 as the IMPACT-WATER model, after being linked ('married') to a water module (Water Simulation Model). In 2009, it was once again coupled: IMPACT married the DSSAT cropping system model to assess some impacts of climate change. Its equations, such as the equation used to calculate child malnutrition examined earlier, were thus transmitted to its descendants (Figure 1).

Global models may converge in their results, but their consanguinity means their convergence does not indicate their validity as two models cannot be used to achieve a triangulation concerning a given result.

Alternative Models?

The deficiencies of dominant global models, such as their inability to consider needs

a variety of scenarios (Dorin et al., 2011). As opposed to most models, it is not based on equilibrium theory. It relies on a direct match between the kilocalories that are produced and those that are needed. Several scenarios radically different from those of other models were produced. They include normative considerations such as sustainable food production and the reduction of inequalities in food and health. Most importantly, this model proposed to follow the flow of calories instead of prices.

Although Agrimonde did contribute to the global debate on the food regime, its international impact was quite limited. The scenarios based on the 'sufficiency narratives' were especially difficult to integrate in the broader debates (Labbouz, 2014). Instead of maximizing production, such scenarios set as an aim the limitation of production once repletion has been achieved, i.e. once the food needs of the population have been satisfied. This was not an appealing aim for many members of the modelling community. Moreover, entering modelling platforms proved very difficult for this model because it had very different structural properties. Regrettably, a model that is 'too original' cannot be integrated while one that recycles modules, equations and datasets used in previous models is easily welcomed.

We conclude that, yes, models do breed. They have proliferated within a very small genetic pool. But they have not done this on their own. Their interactions with modellers and users were crucial in this process. Models may marry, but these are arranged marriages where modellers are the matchmakers. The reasons a model may become dominant or extinct are largely found in the interactions within the epistemic community producing and using models.

Epistemic Communities and Their Models

The term 'epistemic community' designates the networks of professionals with a recognized competence and expertise in a specific field, who appear legitimate to produce relevant knowledge necessary to support public policies in that field (Haas, 1992). The economists, engineers, computer programmers and systems analysts who elaborate global models make up such an epistemic community. The interactions among them, between them and their clients as well as between them and their models have largely contributed to shaping both what these models are and their fates in the larger construction of the food regime.

The Fate of Models in Clients' Hands When Clients Are Modellers

The rise of modelling relying on system dynamics, economic theory and large datasets took place initially in a variety of fields in the United States. It led to a hegemony of rational choice theory and of models as an inevitable tool to manage large systems. This process occurred in the United States in the 1970s in the field of water management, for example (Espeland, 1998). The rise to hegemony of the modelling approach was possible because its promoters managed to convince clients of the usefulness of their models. And this was possible because their clients shared the world view expressed by the modellers.

When asked why a model becomes dominant or extinct, a modeller often answers that models that become extinct did so because they were bad models. This begs the question of what is a bad model. As opposed to hydrological models, global food models cannot be calibrated. Indeed, no independent dataset exists that can allow us

to confront the results generated by a global food model. When the model IMAGE-2 was run to simulate the period from 1900 onwards, it reflected very accurately the situation. But its authors became aware the datasets they used to validate their model had been reconstructed by models structurally similar to IMAGE-2 (Costanza et al., 2007). Their exercise was thus futile. Global climate models face similar problems of data availability, yet they undergo numerous validation processes (Edwards, 1999; Guillemot, 2010). The rich network of weather stations around the world allows climate modellers to attempt a validation process that is only partially undertaken by global food modellers. Thus, a model is not 'bad' because it cannot be calibrated or because it has been invalidated. A model is 'bad' because the epistemic community has not found it to be useful.

How does an epistemic community sift through existing questions and methods to produce the ones it deems useful? This social process involves interactions between modellers, their peers and their clients. For example, when six American agricultural economists, among whom Tim Josling and Alex McCalla, created the International Agricultural Trade Research Consortium (IATRC) in 1978, they were spearheading macroeconomic modelling. With funding from the Ford Foundation, this think tank tackled a fundamental problem: their partial equilibrium models relied on world-market prices as inputs. But the United States and Canada's contribution was so overwhelming that their domestic policies determined the prices of world cereal markets. The outputs thus contradicted the inputs. The IATRC needed to develop a new method (Josling and McCalla, 2010). It organized comparisons between several international models produced by the FAPRI, the USDA, the University of Michigan and the IIASA and the INRA. The IATRC economists shared the conviction that free trade was necessarily good and a completely liberalized agricultural sector would necessarily function best. They borrowed from other models only what was compatible with this premise.

A number of these American modellers pursued their work within international institutions. Tim Josling, for example, went on to the FAO to set up databases of two indicators: Producer and Consumer Subsidy Equivalent (PSE and CSE). PSE estimates the transfers from domestic consumers and taxpayers to farmers under a set of agricultural policies. These indicators introduced a distinction between subsidies deemed to impact market prices and subsidies that didn't impact market prices. This method was then carried over to the OECD in 1982 and led to the MTM model, a macroeconomic model that quantifies the impact of state support in terms of trade distortion. This process led to two important transformations. First, the concepts of 'decoupling' and of 'trade distortion' became hegemonic (Fouilleux, 2000). They are based on the premise that agricultural markets exist as autonomous entities, quite independently of the social and political contexts in which agriculture is carried out. Second, international equilibrium models were effectively black-boxed as the necessary tools to represent world markets and assess the effects of PSE and CSE in terms of price distortions. Modellers in effect penetrated their future clients when they joined institutions in the late 1970s dedicated to policymaking. There, they shaped datasets and approaches that informed later models that these institutions were to call upon.

Modellers joined international institutions at a time when the latter developed macroeconomic models. This allowed these institutions to remain visible as producers of knowledge and to acquire credibility within the new paradigm of world food security. In the 1970s, FAO defined food security in terms of adequate availability

in spite of crop failures or price fluctuations. The models estimated such availability strictly in terms of revenues and food prices. Though such an estimation shrinks the broader understanding of food security as defined by international institutions, it allowed them to take part in the new paradigm. For example, in 1993 the FAO developed the WFM, a partial equilibrium model based on the IFPSIM model. By the end of the 1990s, an international network of macroeconomic modelling was sharing its datasets located in the FAO, the World Bank, the USDA, the OECD, and the GTAP. This network also shared its paradigmatic formulation whereby individual utilities aggregate into the global well-being, a process made possible by the equilibrium of national and international markets.

More recently, institutions such as the FAO have changed their policy and now want to act as critical purchasers of strategically chosen pieces of research, instead of producers of research. As modellers have been migrating to international institutions early on, the clients of modellers have themselves often been modellers for a long time.

Epistemic Communities from Bibliometric Analysis

The overall epistemic community working on food and agriculture at the global scale is so vast and its academic production is so large that a bibliometric analysis can be useful to provide an overview of its structure. We used the free access software CorTextT to identify networks of authors, and cited authors. We analysed two corpuses of scientific papers, one dealing with global food security, the other with international agricultural trade. We composed each corpus from the ISI Web of Knowledge over the period 1974–2011. We used the keyword search ‘world food security OR global food security’ and identified 1,763 papers. We used the keyword search ‘international food trade OR international trade agricult*’ and identified 1,814 papers. We used CorTextT to analyse the metadata of these publications. The CorTextT platform reveals and maps the links between authors, concepts, references and institutions. This allowed us to locate modellers and global models in the overall epistemic community focused on food and agriculture at the global scale.

Figure 2 shows the map produced by CorTextT using the international trade corpus. The authors and institutions cited appear in red circles. The blue circles indicate the authors who publish. The size of the circles is proportional to the number of citations or publications. The large circles thus indicate influential sources of legitimate knowledge. Institutions such as the FAO, the World Bank, the WTO, the USDA, the OECD, the WTO and the WHO as well as the European Commission therefore appear prominently as sources of knowledge. Anthropological fieldwork in the World Bank highlights this strategy (Goldman, 1997). Modelers such as Kym Anderson, Arjen Hoekstra, Tim Josling, Mark Rosegrant, Will Martin, and Jikun Huang appear as important sources of knowledge who both publish a lot and are cited a lot.

Although this corpus was not constructed using a keyword containing ‘model’ or ‘modeling’, by far the most prominent scientists contributing legitimate knowledge are modellers. Institutions that produce the datasets used in their models also figure prominently as sources of legitimate knowledge. This is testimony to the weight of global models in the scientific discourse concerning food and agricultural international trade. Of course, such a bibliometric analysis cannot show users of global models, such as private corporations, who do not publish. It also shows disproportionately authors who publish in English language journals. Additionally, it reflects

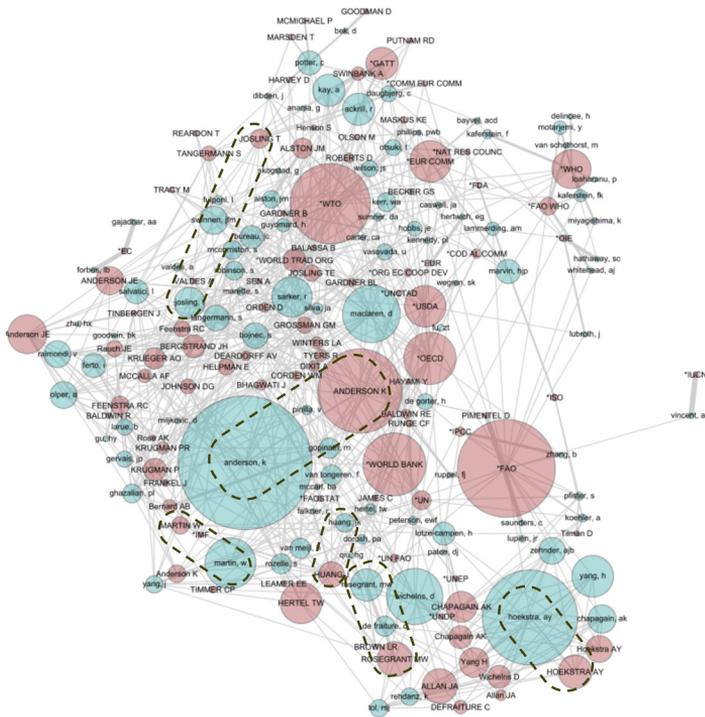


Figure 2. Network of authors and cited authors and institutions, based on the analysis of the international food and agricultural trade corpus with the CorTexT digital platform.

Note: Red circles correspond to cited authors and institutions (legitimate sources of knowledge). Blue circles correspond to authors (producers of knowledge). The thickness of lines as well as the size of the discs is proportional to their weight. Dashed ovals indicate authors that both publish a lot and are cited a lot. Some authors appear several times. This is an anomaly caused by different spelling of their names leading CorTexT to distinguish them.

metadata rather than content and modellers may also publish articles unrelated to modelling. In spite of these limitations, this bibliometric analysis demonstrates the numerous interactions between modellers, data providers, institutions using global models. Such thick networks are indicative of a thriving epistemic community.

Conclusion

Global models of food production and consumption appear to be neutral and apolitical. Yet, when we open them and examine the causal relations their equations express, their political nature becomes apparent. Such power relations were essentialized, i.e. made to appear natural, because they match the world view of the modellers and of the model users. Models that became dominant use prices as a proxy for needs, thereby representing only demand instead of needs. They use elasticities to calculate the development food production should follow. This means that states, or regions, with the lowest marginal production cost for a given foodstuff are inevitably invited to specialize in that production and international trade is inevitably

supposed to grow. Dominant models use a representation of malnutrition that links it to food production, thereby leading mechanically to recommend a greater production to solve this problem. Recent dominant models represent the world as a series of pixels. The grid size within pixel-based representations erases all production units smaller than a pixel from the map. These are all important constructions of power relations. The representations that successful models generate suit several features that match a very specific structure of domination.

Clearly, models that rose to prominence did so because they circulated in dense networks of modelers and users. Alternative models that attempted to track the flow of calories, for example, were unable to integrate such thick networks. Their contribution to the debate concerning the global food regime thus remained marginal. Successful models embedded and thus promoted a structure of domination that suited their users' conception of a legitimate government of food production: one that led to ever increasing international trade and showed investments in agriculture and agricultural productivity as solving hunger.

Smallholders seem erased from the representation of global food production within dominant global models. Yet, the overwhelming importance of smallholder farming is undeniable both in terms of food production and in terms of its role within commercial farming. Indeed, the individuals involved in commercial farming as labourers, for example, are often engaged simultaneously in subsistence farming. The structural difficulty for dominant global models to include smallholder farming raises the question of their usefulness.

Global models that rose to dominance proved very successful at constructing a representation of the world that legitimizes the activities of certain actors, such as foreign investors who claim to develop potential yields in places suffering from inefficient or inexistent agriculture. They also legitimize productivist policies and the promotion of a deregulated international market of agricultural products. Yet, the same models show grave deficiencies. They are structurally unable to predict a food crisis such as arose in 2008. So, the success of global models stems from their capacity to effectuate a world that matches both the structure of signification modellers adhere to and the structure of domination their clients champion.

Global food production models that rose to dominance did so because the epistemic community that generated them enrolled enough users into a dense network. An approach rooted in actor-network theory allowed us to demonstrate this. These models embedded very specific power relations within the causal relations expressed by their equations. This led them to promote a very specific food regime that matches a global structure of domination the users of these models sought to establish. An approach rooted in structuration theory allowed us to demonstrate this. Combining both of these approaches was necessary to understand the contribution of global models to the food regimes. They effectuate the food regimes their champions wish to establish far more than they describe the existing world in a 'neutral' fashion.

Note

1. Acronyms of the global models cited in the article: DSSAT: Decision Support System for Agrotechnology Transfer ; GAEZ: Global Agro Ecological Zones ; GOL: Grain-Oilseed-Livestock Economy Model; IFPSIM: International Food Policy Simulation Model; IMAGE-2: Integrated Model to Assess the Global Environment ; IMPACT: International Model for Policy Analysis of agricultural Commodities and Trade; LAWM: Latin America World Model ; MISS: Modèle International Simplifié de Simulation ;

MOIRA: Model of International Relations in Agriculture ; MTM: Ministerial Trade Mandate model ; SWOPSIM: Static World Policy Simulation Model ; WFM: World Food Model.

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