A stylised mathematical model of national-level food system security

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Abstract. Global food security is threatened by various endogeneous and exogeneous, biotic and abiotic factors, including a rising human population, higher population densities, price volatility and climate change. Perturbations to the global food system have a direct effect on the security and resilience food systems. These effects are felt, in different ways, by both producers, processors and consumers. Various mathematical and computational models exist to understand food systems' responses to shocks and stresses, but most models are tailored to making predictions of specific food systems and contexts. Here, we present and analyse a stylised mathematical model of a national-level food system that incorporates dynamic interactions between domestic production of a food commodity, international trade, domestic demand and consumption, and food commodity price. The model exhibits two dominant modes of behaviour, unsustainable and sustainable domestic production, the stabilty of which depends on a balance between the strength of internationa trade and local production costs. As an example, we fit our dynamic systems model to data from the UK pig industry using Bayesian estimation.

Contents

1 Introduction

Food security is defined as "when all people at all times have physical and economic access to sufficient, safe and nutritous food to meet their dietary needs and preferences for an active and healthy life" (FAO. 1996). The realisation of food security depends on the three pillars of access, utilisation and availability (Maxwell 1996; Barrett 2010), and therefore is an outcome of coupled agricultural, ecological and sociological systems (Hammond and Dubé 2012; Ericksen 2008; Ingram 2011). In recent years, the resilience of food security has become a priority area of research (e.g. Nyström et al. 2019; Tendall et al. 2015; Béné et al. 2016; Seekell et al. 2017) as biotic and abiotic, endogeneous and exogeneous demands on food systems grow, including the deleterious effects food systems have on their own environments (Springmann et al. 2018; Strzepek and Boehlert 2010). The challenge of food security is for food systems to expand their production capacities while both remaining resilient to unpredictable perturbations and limiting their effects on the environment (Ericksen et al. 2010).

Food system research is inherently transdisciplinary (Drimie and McLachlan 2013; Hammond and Dubé 2012), of which one strand is computational and mathematical modelling. The utility of quantitative modelling is the ability to build and perturb realistic models of food systems to project important outcomes, such as food production levels, farmer profitability, envirnomental degradation, food waste, and consumer behaviour (e.g. Springmann et al. 2018; Marchand et al. 2016; Sampedro et al. 2020; Suweis et al. 2015; Scalco et al. 2019). The difficulty in modelling food systems is their complexity, often requiring large models in detail (i.e. number of parameters), scope (i.e. number of dynamic variables), or both, which are challenging to analyse, and even more challenging to statistically estimate from noisy real-world data. A handful of authors have used relatively simple, theoretical models to understand the activities of global food system. For example, Suweis et al. (2015) link population dynamics to food availability and international trade using a generalised logistic model. Similarly, Tu, Suweis, and D'Odorico (2019) adapt the analytical framework of Gao, Barzel, and Barabási (2016) to determine that the global food system is approaching a critical point signifying loss of the global food system's sustainability. Moreover, Ngonghala et al. (2017) demonstrate the dynamical interactions between human poverty, economic growth, and disease from simpled models of coupled differential equations. Simplified models of complex systems elicit specific explanations and hypotheses of how systems work (Smaldino 2019), which are, arguably, more amenable to direct hypothesis-testing from available data than larger models that involve a many more causal pathways and potential redundancies.

Such *stylised* models are staples of scientific disciplines such as ecology (e.g. May 1973), evolutionary biology (Boyd et al. 2003), epidemiology (Kermack and McKendrick 1927), and physics (Strogatz 1994).

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