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Will the world have enough to eat?

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The food price spike in the first half of 2008 has increased concerns about the global supply of food in the future. Technically it seems possible to feed the nine billion people who are expected two or three times over by mid-century. However, diminishing returns, rising input prices and handicaps of less-favored areas will make the world food economy run up against a ceiling long before the technical potential has been realized. On the basis of an analysis of the literature we argue that if the long-term price decline of food in the 20th century were to change, short time horizons of private and public actors pose special risk because these may prevent timely investment in increasing the world's capacity for food production. Governments have a number of options to mitigate this risk by influencing the supply and demand for farm products, investing in research and infrastructure, and reducing the price instability in agricultural markets.

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Introduction

In the past, hunger was caused by poverty *and* scarcity. In the 20th century, it was caused by poverty amidst abundance. It made poverty reduction the main target of international campaigns to improve food security (e.g. in the context of the Millennium Development Goals). However, will food remain abundant in the coming decades? Or will the hunger of the poor once more be exacerbated by rising food prices? The price spike in 2007–2008 increased the number of undernourished people in the world with 40 million. Meanwhile, agricultural prices are back at their 2007 level, indicating increased price instability (in itself serious enough) rather than chronic scarcity. It is expected that until 2018, prices will rise modestly above those in the decade before 2007 [1]. Yet, for the longer term future it is less sure that new scarcity can be avoided. By 2050, the global demand for primary biomass for food will have doubled, because of further increases in world population and consumption of animal foods [2–4]. Although there is a boom in consumption in China and India, global demand growth is actually slower now than during the past 50 years. In those decades, the increase in global production exceeded that in demand [5] causing food prices to decline. A key question is whether this strong supply response will repeat itself in the coming decades or whether new scarcity should be anticipated. Model studies try to answer these questions, but the world food economy is too complex to allow reliable long-term predictions. Nevertheless, we do know a few things. This article reviews the literature to explore whether the globe can and will produce sufficient amounts of food to feed its population over the coming 40 years. Both technical potentials, limiting factors and risks are assessed.

Technical potential for food production

We know that the main sources of agricultural growth in the 20th century are drying up. Theoretically the global agricultural area could still be expanded by 80% [6,7], but most spare land is little suited for productive agriculture. Only Africa and Latin America have significant reserves of suitable land. In several grain belts, especially in Asia, freshwater supply for irrigation is running dry. And yield potentials of major food crops have stagnated [8,9], even though there might still be some room for lifting potential yields along conventional pathways ([8–10]; Shearman et al. [49]).

On the other hand, existing potential yields of crops leave significant room to raise production. A simulation study in the 1990s estimated that, if all suitable land and available water would be used according to technical optima, the world could produce 72 GT of grain equivalents [6,11]. This is 10 times current production — enough to feed the expected world population by 2050 five times over with an affluent diet. But this estimate was overoptimistic. It assumed yields of 90% of the theoretical potential, while in practice it is hard to achieve 80% [8,12]. It also ignored human settlement, biodiversity conservation, and nonfoods (including biofuel), which may claim 20–40% of land suitable for agriculture. These factors roughly half the above-mentioned potential [13•]. Furthermore, significant wastage of food by consumers cannot be prevented (Rathje and Murphy [50]; [14]). Assuming a global potential of 36 GT of grain equivalents and an unavoidable waste of 20%, twice the world population expected in 2050 could be given an affluent diet [13•].

In addition, other options for raising food supply exist:

- Improvement of plant metabolic efficiencies, for instance by changing C_3 crops into C_4 crops, might allow a further stretching of potential crop yields even when traditional possibilities for achieving this aim have been depleted [15••].
- Novel nonfarm biomass production systems could be developed, such as new marine systems (e.g. seaweed plantations) [16] or the cultivation of algae or bacteria (Hejazi and Wijffels [51]; [17]).
- The conversion of primary biomass into foods or nonfoods could be improved. There is room for raising feed conversion ratios of livestock in developing countries ([18]; Bouwman et al. [52]). A shift to animal species with more favorable conversion ratios (e.g. herbivorous fish or mini-fauna) (Nakagaki and De Foliart [53]; [19]) or to meat substitutes based on plants or fungi would also reduce feed requirements. Moreover, new biorefinement techniques may be developed for upgrading wastes, residues or plant parts that are now underutilized.

It may thus seem technically possible to feed the expected world population by 2050 at least two times over. However, realizing the above potentials is an enormous challenge. In Europe and Asia, farmers presently achieve 25–60% of existing potential yields (Pinnschmidt et al. [54]; [12,20,21]). Raising this to 80% requires novel solutions for controlling biotic and abiotic stresses. Meat substitutes and animal species that need a lower biomass input are hardly accepted by consumers (see e.g. [22] for meat substitutes). Most of the other options are remote opportunities. Improving plant metabolic efficiencies, for example, involves a much higher order of complexity than breeding for improved plant architecture [15••,23••].

Economic constraints

Technical options for food production can be seen as constituting a production possibility landscape. This landscape has human-controlled energy input, complexity levels, and biomass output as dimensions and has a hill-like form as depicted in the left-hand panel of Figure 1. At low levels of energy input, simple production systems have better input–output ratios because they need less energy for maintenance. Systems that are efficient at higher levels of energy input tend to be more complex. The historical growth in biomass output can be seen as the climbing of this production possibility hill by increasing the energy input while shifting to new levels of complexity from time to time to postpone diminishing returns (cf. [24,25]). Exploiting the technical potential for food production means continuing this climbing up to the potential agricultural production, or shifting the potential upward through genetic improvements.

Economically, the production possibility landscape translates in a series of production functions and innovation possibility sets that inform the production and investment decisions of private and public actors (see the right-hand panel of Figure 1). However, economic constraints will prevent these decisions from fully realizing the potential. Apart from specific constraints that might be relaxed (say, underdeveloped markets for land or credit), there are more fundamental reasons why the maximum of the production possibility hill will not be reached.

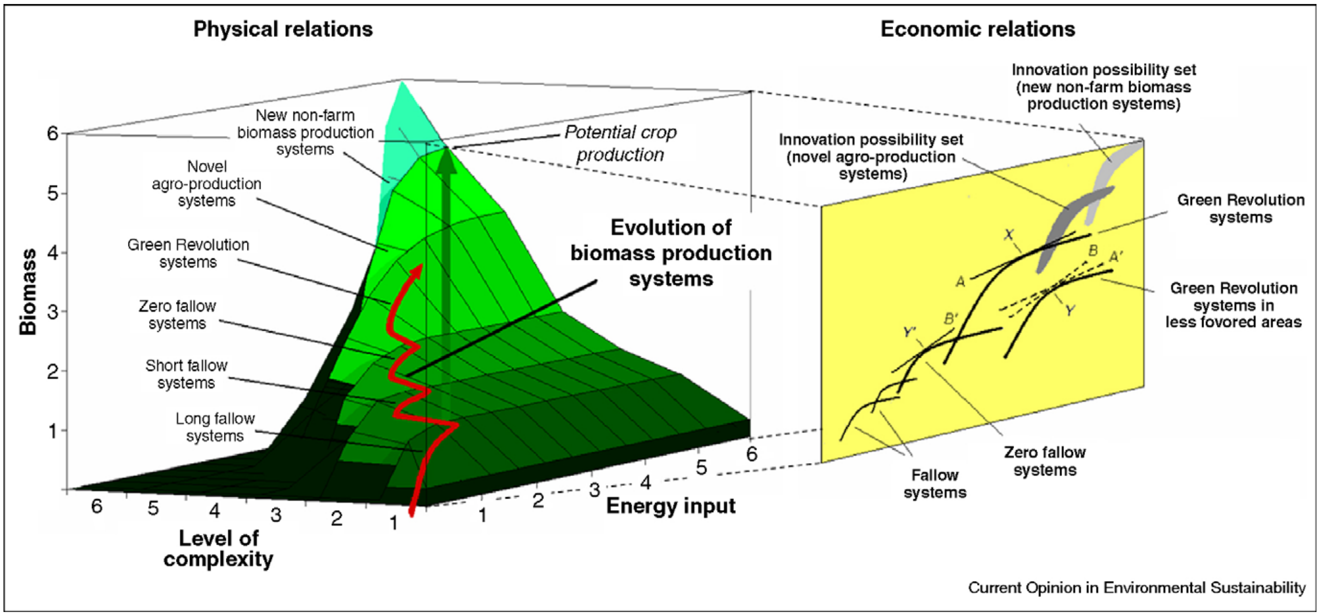
First, producers maximize profit rather than output. Because of diminishing returns, they stop short of the maximum that the techniques they know allow. For instance, raising food and feed crop production to 36 GT of grain equivalents, as assumed above, requires an 600% increase in the global irrigated area. Diminishing returns to irrigation investment will make the real increase a far cry from this.

Second, pushing back diminishing returns requires investment in research and human capital to extend existing production functions, but such investment is constrained by its profitability. In the 20th century, agricultural research gave high returns [26], but this was thanks to cheap fertilizer, and to the room, which is now being depleted, for breeding plants that could transform more fertilizer into harvested parts by improving plant architecture, crop duration and the timing of crop development. Whether research for realizing the remaining potentials for raising food production will give comparable returns is highly uncertain, despite all progress in ICT and biotechnology.

Third, costs also influence production decisions. The progressive depletion of the world's reserves of fossil fuels and phosphate rock [27,28] will raise the costs of many farm inputs, especially fertilizers. Improving the efficiency by which fertilizer is produced and used could counteract this. But the energy efficiency of modern ammonia plants is approaching the chemical maximum [29,30]. And improving fertilizer use efficiencies will be complicated by the need to raise production on less suitable soils.

Fourth, in many regions producers face relatively high risks and transaction costs, and unfavorable price ratios. Consequently, they may opt rationally for technologies that give a lower output per hectare. These may be efficient with relatively high risk or at low inputs, because simple production systems need less inputs for maintenance. Thus in Latin America, strong inequality in land ownership has induced a labor-saving and capital-saving development that gives limited yields (cf. [31]), while in sub-Saharan Africa, natural disadvantages and poverty traps have caused an agricultural revolution to stop shortly after it started [32•,33]. As these regions contain half the

Figure 1



Conceptual representation of biophysical and economic relations in raising food production. The left-hand panel gives the relationships between human-controlled energy input, complexity of food production system management, and output of usable primary biomass in an area. The green zones are production possibilities at a given complexity level. At low levels of energy input, simple food production systems have better input–output ratios because they need less energy for maintenance. Systems that are efficient at higher levels of energy input tend to be more complex in terms of their management and control. The red line is a stylized representation of the historical evolution of food production systems. The green arrow indicates potential agricultural production (cf. Van Ittersum and Rabbinge [42]). The right-hand panel shows how the evolution of production systems translates into (subjective physical) production functions. A, A′, B and B′ are lines with input–output price relations as slopes. Producers in favored areas produce at point X, producers in less-favored areas at point Y′. (B′ has a higher intercept with the *Y*-axis than B meaning that Y′ gives a higher profit.) Further increases in production require investment to shift production functions toward innovation possibility sets.

world's unused potential for farm production [6], the consequences for global food supply are far-reaching.

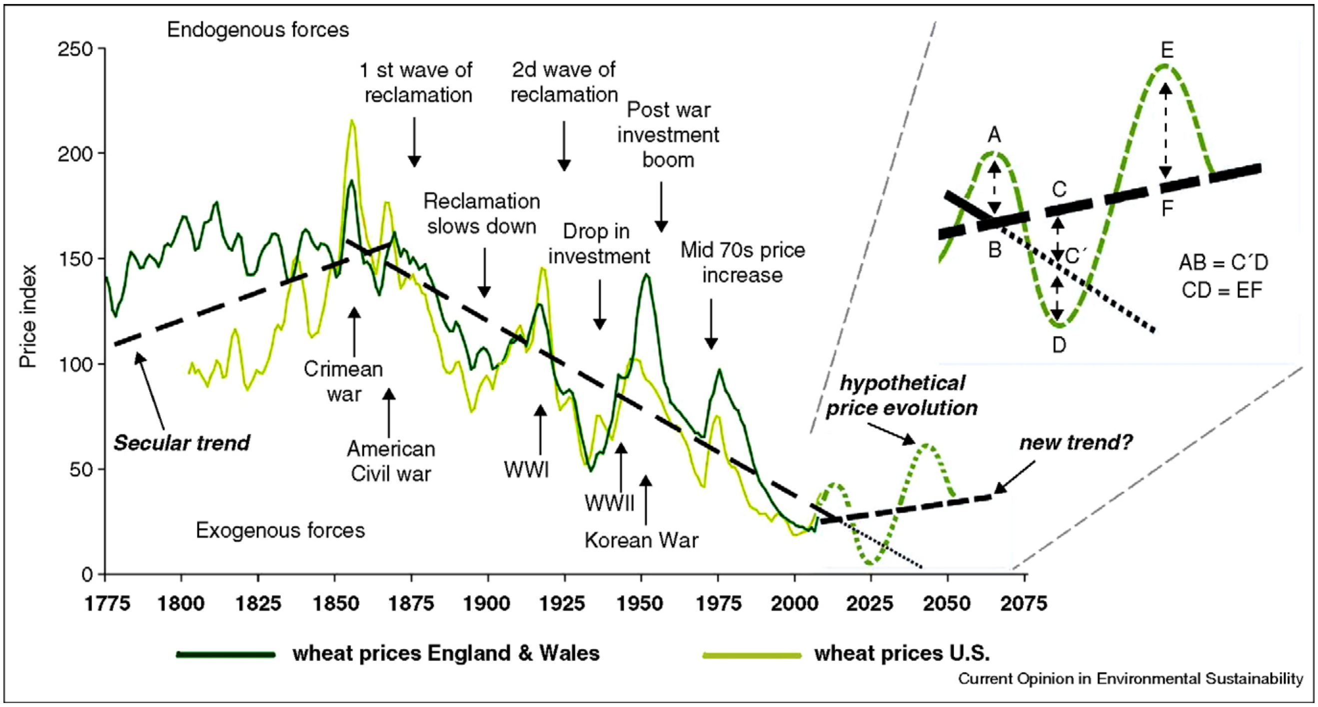
Finally, it is uncertain how the competition between foods and biobased nonfoods will evolve. Biorefinement will reduce the area requirements per unit of nonfoods, which will not only moderate this competition (second-generation biofuels, etc.), but also reduce the cost price of nonfoods, which will have an opposite effect [34].

As always in human history, global food supply will reach an economic ceiling long before the technical potential at the frontier has been exhausted. Adequate policies can push the ceiling upward, but it requires new breakthroughs that may be hard to realize. Seen in this light, the technical potential for feeding two or three times the expected population may prove restrictive.

Myopic expectations

In the second half of the 19th century, new industrial breakthroughs broke the age-old tendency of population growth to raise food prices. Falling transport prices, cheap fertilizer and fossil substitutes for farm-produced materials and energy sources induced a long-term price decline in international food markets [35]. The considerations presented in the previous sections do not allow any firm conclusion, but suggest that a new trend change in the coming decades cannot be excluded. The long-term price decline in the 20th century may cease or give way to a long-term increase in food prices. If so, a special risk arises during the transition. Both private and public decision-makers have short time horizons. If current prices are high (low), they tend to expect that prices will also be high (low) in the future. Such 'myopic expectations' can cause endogenous price fluctuations coupled to an alternating overshooting and undershooting of trend investment ('cobweb cycles'; cf. [36,37••]). This is illustrated by Figure 2, that shows that historical wheat prices have fluctuated along a declining trend. This was partly due to exogenous shocks (in particular, major wars), but the available literature (e.g. [38,39], P Díaz Jéronimo, MSc thesis, Wageningen University, 2006) suggests that endogenous influences also played an important role (see factors indicated above the graph). In line with this, the rise in food prices in 2007–2008 can be seen at least partly as an effect of the low prices in the 1980s and 1990s which caused a new undershooting of trend investment. Not least, the growth rate of global public agricultural research

Figure 2



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Indexes of real wheat prices in the US and England and Wales, 1800–2007, and hypothetical evolution after 2007. Prices up to 2005 are five-year moving averages, with 1901–1905 = 100. Prices in 2005–2007 are annual prices with the same base years. Sources: [43–48]; USDA National Agricultural Statistics Service, *Crop Production and Agricultural Prices*, (http://www.ers.usda.gov/Data/Wheat/WheatYearbook.aspx); USBL Bureau of Labor Statistics, *Consumer price index* (http://www.bls.gov/CPI/). The hypothetical evolution after 2007 assumes a trend change combined with a continuous cobweb fluctuation. If AB and C′D are the amplitude of the cobweb fluctuation under the old trend, the initial amplitude under the new trend is CD and EF.

expenditures fell by two-thirds in that period [40,41•], while private investments also declined in the 1990s. By the same token, the higher prices that have been caused by this underinvestment may now prompt a rapid exploitation of the last margins for cheap increases in the global farm output that still exist in countries such as Brazil and Russia. The risk is that this will induce new price falls after some years, and that these will once more squeeze longer term investment in the world's carrying capacity for food production. If such a development were to coincide with a change in the long-term trend, the result could well be a period with stronger price rises than occurred in 2007–2008, with all its consequences (see the hypothetical price evolution between now and 2050 in Figure 2).

Conclusions and policy implications

Technically there is potential for feeding two or three times as many people as anticipated for the year 2050. However, economic and social factors determine that global food supply is likely to reach a ceiling long before the technical potential has been realized. Myopic expectations resulted in lower investments in agricultural research over the past decades. If this is combined with a trend change in food prices in the coming decades, which is not unlikely, global food availability is at stake.

Can the risk of unnecessary scarcity in food markets be reduced? There are various options for moderating a possible trend change. Governments could stop supporting biofuels. They could discourage the consumption of livestock products with the most unfavorable feed conversion ratios (especially feedlot beef). They could forcefully support smallholder-based agricultural growth in developing countries. And they could join hands, support education, and create a global social security system, which would moderate the growth in world population.

Likewise, there are options to limit cyclic underinvestment. Governments could raise investment in irrigation and in research for sustainable yield increases, nutrients recycling, biorefinement, effective meat substitutes, and new nonfarm biomass production systems. Additionally, they would be well-advised to reconsider the direction in which international agricultural trade reforms are moving, as the current liberalization increases the scope for endogenous price fluctuations.

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