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On food security and the economic valuation of food

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ABSTRACT

The paper presents an economic evaluation of food and the cost of food insecurity. Building on behavioral regularities of consumer behavior, the analysis estimates the benefit of food at the individual level and at the world level. It finds an inverted-U relationship between food benefit and income. At the individual level, the "food benefit/income" ratio starts at 0 under extreme poverty, increases with income to reach a maximum of 4.4 when income per capita is around $13,000, and then declines slowly as income rises. The paper shows very large aggregate net benefit of food. The analysis also evaluates the cost of food insecurity. It shows that aversion to food insecurity is pervasive, the coefficient of relative risk aversion to food insecurity being around 2.7. The analysis evaluates empirically the cost of food insecurity. We report the cost of food insecurity under alternative scenarios, documenting that it can be large in situations of exposure to significant downside risk.

1. Introduction

Food consumption is required to support human life. Any situation where individual food consumption fails to sustain a healthy diet raises concerns about food insecurity (Webb et al., 2006; Leathers and Foster, 2009; Barrett, 2010; IFPRI, 2014). FAO (1996) defines food security as situations where "all people at all times have the physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". Thus, under food security, no individual faces hunger or starvation. Alternatively, food insecurity arises when some individuals face limited or uncertain access to nutritionally adequate and safe food. Situations of undernutrition are pervasive. FAO (2015) reported that 795 million people were chronically undernourished in the years 2014–2016, representing 10.9% of the world population. Most live in developing countries. This is important since food security is an important component of the process of economic development (e.g., Fogel, 2004). Over the last few decades, improvements in food security have come from increase in agricultural productivity as well as reduction in extreme poverty (Charles et al., 2010; FAO, 2015).

The importance of food provides strong arguments to motivate the analysis of food security issues (e.g., Newbery and Stiglitz, 1981; Barrett, 2010; FAO, 2015). Recent increases in food price volatility and adverse effects of climate change on the food system have raised renewed concerns (Gouel, 2013; Nelson, 2014). But assessing the economic value of food and of food security remains challenging (Webb et al., 2006; Cafiero, 2013). This is due in large part to the complexities of the world food system. Food production varies greatly over space and depends on food products, prices, technology and local agro-climatic conditions. Food consumption also varies across individuals/countries depending on tastes and preferences, prices and income distribution. And individual access to food is complex. In general, food insecurity varies over time and across space. It depends on food availability. Food insecurity develops in periods and locations where food scarcity occurs due to high food demand (e.g., from a rapid rise in population) and/or to food production shortfalls (e.g., from a drought). But food insecurity can also arise when food is plentiful. As argued by Sen (1981), food insecurity (or even famine) can occur when consumers are too poor to acquire a nutritionally adequate diet. In this case, food access is constrained by household purchasing power. Finally, the consumer value of food relates to its nutritional and health attributes that remain difficult to measure (Barrett, 2010). These complexities have made it difficult for economists and policy analysts to assess food security issues and to design and evaluate programs intended to reduce food insecurity (Webb et al., 2006). Thus, there is need for a refined exploration of the economics of food and its

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linkages with the empirical assessment of the value of food and of the welfare evaluation of food security.

The objective of this paper is to develop new insights into the economics and welfare of food and food security. For simplicity, our analysis focuses on the case where food is treated as an aggregate good.[2] The analysis starts with the microeconomics of food demand. It then examines the evaluation of consumer welfare at both the micro level and the aggregate level. The paper addresses two key questions. What is the value of food? And what is the cost of food insecurity? In the process of answering these questions, we provide new and useful information to economists and policy analysts interested in the food sector and in the evaluation of policies affecting food security.

The paper makes three contributions. First, it develops a conceptual framework to evaluate the economics and welfare of food. Our analysis relies on consumer's willingness-to-pay for food. We propose to measure the willingness-to-pay for food using a benefit function. As discussed in Luenberger (1992, 1995, 1996), the benefit function has two attractive properties: (1) it provides an evaluation of consumer willingness-to-pay; and (2) it can be easily aggregated (with aggregate benefit being the sum of individual benefits). This paper seems to be the first paper using the benefit function in the investigation of the value of food and food security. Applied to the consumer level, our approach stands on strong foundations of microeconomic theory. We develop linkages between Engel's law (expressing the relationship between food expenditure and household income) and food benefit (measuring the consumer's willingness-to-pay for food). And following Sen (1981), our analysis also captures how limited purchasing power can affect the consumer's willingness-to-pay for food. This allows us to obtain new relationships between income and food benefit. And applied at the aggregate level, our approach provides a basis to evaluate the economics and welfare of food and food policy for human society. Importantly, the analysis allows for consumer heterogeneity (especially heterogeneity in household income).

The second contribution is to use our conceptual framework to support an empirical evaluation of the value of food. The analysis starts at the micro level and then proceeds at the aggregate level where both supply factors and demand factors are discussed. On the demand side, we link demand elasticities with willingness-to-pay measures. Food being a necessity, the approach reflects that a minimum consumption of food is required to sustain individual life. It allows for situations where individual willingness-to-pay is constrained by ability-to-pay. Building on behavioral regularities of consumer behavior, the analysis estimates the benefit of food at the individual level and at the world level. It finds an inverted-U relationship between individual food benefit and income. On a per capita basis, the "food benefit/income" ratio starts at 0 under extreme poverty, increases with income to reach a maximum o of 4.4 when income per capita is around $13,000, and then declines slowly as income rises. Applied to the world level, the analysis also shows that the aggregate net benefit of food is very large.

The third contribution is to evaluate the cost of food insecurity. We define food insecurity as the risk associated with individual access to food.[3] In this context, we propose to measure the cost of food insecurity by the consumer willingness-to-pay to eliminate this risk. We establish linkages between the Hicksian price elasticity of food demand and the degree of aversion to food insecurity. The coefficient of relative risk aversion to food insecurity is found to be around 2.7, indicating that aversion to food insecurity is pervasive among households. The approach provides a basis to evaluate empirically the cost of food insecurity. We report estimates of the cost of food insecurity under alternative scenarios. The results show that the cost of food insecurity can be large in situations of exposure to significant downside risk. Applications at both the micro level and the aggregate level illustrate how the analysis can help economists and policy analysts assess food insecurity issues and evaluate food policy.

The paper is organized as follows. The analysis starts with a review of empirical regularities related to the demand and supply of food. This includes Engel's law and supply/demand elasticities of food. The consumer benefit of food is then evaluated at the individual level and at the world level. Next, we examine the measurement and valuation of food insecurity. Finally, concluding remarks are presented.

2. Literature review

Much research has been done on the supply and demand of food. Below, we review some key empirical regularities characterizing the economics of food. We start with the consumer side of the food system.

2.1. Food demand

The effects of prices and consumer income on food consumption have been studied extensively (e.g., Pinstrup-Andersen and Caicedo, 1978; Alderman, 1986; Deaton, 1992; Subramanian and Deaton, 1996; Huang and Lin, 2000; Seale et al., 2003; Gao, 2012). From consumer theory, these effects can be expressed in terms of the properties of Marshallian demands. The Marshallian demand for food $x^*(p, I)$ expresses utility-maximizing food consumption x^* as a function of food price p and consumer income I (Deaton and Muellbauer, 1980; Deaton, 1992). In this context, define <u>food purchasing power</u> by I/p, measuring the largest quantity of food that can be purchased with income I. The first empirical regularity relates to the effects of income on food consumption.

2.1.1. A1 (Engel's law): The food budget share $W = px^*(p, I)/I$ declines with consumer income I

This empirical regularity was first noted by the German statistician Ernst Engel in 1857. A1 is now commonly called "Engel's law" stating that poorer families tend to have a larger share of their budget spent on food. Engel's law is well documented and widely used in the evaluation of welfare and poverty (e.g., Chai and Moneta, 2010). It can be illustrated in cross-country analyses of food consumption patterns (e.g., Seale et al., 2003; Gao, 2012). As reported in Table 1, on average, the food budget share $W = px^*(p, I)/I$ goes from 0.526 in low income countries, to 0.347 in medium income countries, and to 0.170 in high income countries (Seale et al., 2003).

By definition, the income elasticity of food demand is $E_I = \partial \ln(x^*)/\partial \ln(I)$. Given $W = px^*(p, I)/I$, the income elasticity can be alternatively written as $E_I = 1 + \partial \ln(W)/\partial \ln(I)$. To the extent that $\partial \ln(W)/\partial \ln(I) < 0$ from A1, this suggests the following corollary.

2.1.2. A1′: The income elasticity of food demand E_I is between 0 and 1, and declines with consumer income I

The properties A1 and A1′ are associated with food being a <u>necessity</u>: human life cannot be sustained without food

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[2] This simplification also means that this paper does not address issues related to heterogeneity among food products (e.g., cereals versus fruits versus vegetables) and/or among nutrients (e.g., macronutrients versus micronutrients). Extending our analysis to examine such issues is a good topic for further research.

[3] As such, our analysis is <u>not</u> about income insecurity or price uncertainty. While there are strong linkages between income, food and food prices (e.g., as analyzed by Turnovsky et al. (1980) and Newbery and Stiglitz (1981)), our investigation focuses on the benefit of food and its implications for the evaluation of food insecurity when consumer's access to food in uncertain. A brief discussion of the differences between our approach and the analysis of food price uncertainty is presented in section 4.

Table 1
Empirical regularities of food demand.[a]

Income level[b]	Low income	Medium income	High income
Food budget share, $W = px^*/I$	0.526	0.347	0.170
Income elasticity, $E_I = \frac{\partial ln(x^*)}{\partial ln(I)}$	0.729	0.602	0.335
Marshallian price elasticity $E_p^* = \partial ln(x^*)/\partial ln(p)$	−0.751	−0.593	−0.307
Income effect $E_I W$	0.383	0.209	0.057
Hicksian price elasticity $E_p^c = \partial ln(x^c)/\partial ln(p)$	−0.368	−0.384	−0.250

[a] Letting p denote the price of food and I be consumer income, $x^*(p, I)$ is the Marshallian demand for food, and $x^c(p, U)$ is the associated Hicksian demand satisfying the Slutsky equation $E_p^c = E_p^* + E_I W$. Source: Seale et al. (2003).

[b] Seale et al. (2003) examine three groups of countries: low-income countries (less than 15 percent of U.S. income level), middle-income countries (between 15 and 44 percent of U.S. income level), and high-income countries (at least 45 percent of U.S. income level).

consumption. From A1 and A1′, when income I decreases, the food budget share increases toward 1 (as individuals spend a larger share of their income on food trying to avoid starvation). Alternatively, when income increases, the food budget share declines (as individuals spend relatively more of their income on luxury goods) and the income elasticity of food also declines. Again, this is illustrated in cross-country analyses of food consumption patterns (e.g., Seale et al., 2003; Gao, 2012). As reported in Table 1, on average, the income elasticity of food demand $E_I = \partial \ln(x^*)/\partial \ln(I)$ goes from 0.729 in low-income countries, to 0.602 in medium-income countries, and to 0.335 in high income countries (Seale et al., 2003). This shows that income is an important factor affecting food demand.

The second empirical regularity relates to the effects of food price on food consumption. This can expressed in terms of the Marshallian price elasticity of food demand $E_p^* = \partial \ln(x^*)/\partial \ln(p)$.

2.1.3. A2: Food demand is price-inelastic: $-1 < E_p^* < 0$

A2 states that a higher food price has a negative effect on food demand, with effects that are less than proportional to the price change, i.e. that food demand is price inelastic. This property reflects the effects of food intake on nutrition and health. Indeed, for any individual, there is a rather narrow range of food intake that generates good nutrition and health. "Too little" food consumption leads to under-nutrition and, in extreme cases, starvation and death. And "too much" food consumption leads to over-nutrition and obesity, with adverse effects on health. In this context, assuming that income is "not too low", the price inelasticity of food demand stated in A2 indicates that consumers facing changes in food price would make modest adjustments in food intake, avoiding either under-nutrition (under a large price increase) or over-nutrition (under a large price decrease).

Table 1 presents an illustration of A2 in the context of cross-country analyses of food consumption patterns (Seale et al., 2003). It shows that food demand is price inelastic ($|E_p^*| < 1$) for all income levels. There is also evidence that the price elasticity of food demand varies with income (e.g., Pinstrup-Andersen and Caicedo, 1978; Alderman, 1986; Gao, 2012). Table 1 shows how the Marshallian price elasticity of food demand changes with income. On average, $E_p^* = \partial \ln(x^*)/\partial \ln(p)$ goes from −0.751 in low-income countries, to −0.593 in medium-income countries, and to −0.307 in high-income countries. In other words, food demand tends to become less sensitive to price (i.e., more price-inelastic) as income rises.

Next, we examine the implications of A1-A1′ and A2 for Hicksian demands. The Hicksian demand for food $x^c(p, U)$ expresses the expenditure-minimizing food consumption x^c as a function of food price p, holding utility U constant (Deaton and Muellbauer, 1980). From duality, Marshallian demand and Hicksian demand are closely related. They satisfy the Slutsky equation $E_p^c = E_p^* + E_I W$, where $E_p^c = \partial ln(x^c)/\partial(\ln(p)$ is the Hicksian price elasticity of demand for food and $E_I W$ is the "income effect". This raises the question: How does the Hicksian price elasticity E_p^c vary with income (Timmer, 1981)? In the context of cross-country analyses of food consumption, Table 1 shows estimates of E_p^c and of the income effect $E_I W$. As expected (from A1 and A1′), the income effect $E_I W$ declines as income rises. Table 1 also shows that the Hicksian price elasticity of demand for food is fairly stable: E_p^c varies from −0.368 for low-income countries, to −0.384 in medium-income countries, and to −0.250 in high-income countries.[4] This gives the following regularity condition.

2.1.4. A3: The Hicksian price inelasticity of food demand is approximately constant for a wide range of income

A3 states that the Hicksian food price elasticity $E_p^c = \partial ln(x^c)/\partial(\ln(p)$ does not vary much with income.[5] Table 1 suggests that, for an average consumer, E_p^c can be approximated as $E_p^c \cong -0.37$ for various income levels. We will make use of this result below.[6] Note that, given the Slutsky equation $E_p^c = E_p^* + E_I W$, the relative stability of E_p^c with respect to income implies that the growing inelasticity of Marshallian demand for food as income increases is due mostly to the income effect $E_I W$.

2.2. Food supply

Next, we examine the supply side of the food system. In general, agriculture is in the business of producing food from agro-ecosystems, using solar energy and other inputs. There has been much research evaluating the many factors affecting the supply of food. Agricultural food production depends on the amount of cultivated land and on yield (production per hectare). During the eighteenth and nineteenth century, the world has seen a steady increase in the amount of cultivated land. Over the last 50 years, cropland has stabilized in North America, Europe and China, but it has continued to expand in Africa, South America, South East Asia and the Former Soviet Union (Ramakutty and Foley, 1999; Headey, 2016). Most of the increase in food production now comes from yield increases and technological progress in agriculture (FAO, 2015).

In this context, how do changes in food prices affect world food supply? Recent evidence on the elasticity of world food supply is given in Roberts and Schlenker (2013). Food supply is equal to yield times the amount of cultivated land. Roberts and Schlenker (2013) find very small effects of price on yield. It means that the effects of price on food production come mostly from adjustments in cultivated land. When applied to disaggregate foods, farmers have the option to switch between crops as relative agricultural prices change. But this substitution possibility declines when considering food at the aggregate level. Let $X^*(p)$ denote the world

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[4] Gao (2012) found similar results. She reported Hicksian price elasticity of demand for food E_p^c to be within −0.2 and −0.4 across a wide range of income (Gao, 2012, p. 40).

[5] Note that the relative constancy of E_p^c may not apply in more extreme situations. For example, Chavas (2013) has argued that the Hicksian food price elasticity E_p^c becomes very small either under starvation or under extreme obesity. In this case, E_p^c would have a U-shape with the U having a "flat-bottom" in the region of relatively good nutrition.

[6] Note that our Hicksian demand elasticity estimate $E_p^c \cong -0.37$ is a little more elastic than the average estimate of −0.27 reported in Gao (2012, p. 40). The implications of this difference are discussed in footnote 12 below.

supply function for food, with $E^s = \partial \ln(X^*)/\partial \ln(p)$ denoting the price elasticity of aggregate food supply. Roberts and Schlenker (2013) find that the aggregate cultivated land and the aggregate supply of food is very price inelastic, with a world price elasticity of supply $E^s = 0.10$. This gives the following regularity conditions:

2.2.1. A4: The elasticity of world food supply is price-inelastic, with $E^s \cong 0.10$

The above regularity conditions are used next in the evaluation of the economic value of food.

3. Measuring the value of food

How can we measure the value of food? A good starting point is given by each consumer's willingness-to-pay for food. Formally, this can be expressed in term of the benefit function. Consider an individual consuming food x and non-food y, and with preferences given by the utility function $u(x, y)$. Define the individual benefit function as

$$B(x, y, U) = Max_\beta\{\beta : u(x, y - \beta) \geqslant U\}, \tag{1}$$

where U is a reference utility level (Luenberger, 1996). The benefit function $B(x, y, U)$ in (1) measures the number of units of non-food the consumer is willing to give up starting with utility U to reach the consumption bundle (x, y). When the price of non-food is normalized to be equal to 1, the benefit function $B(x, y, U)$ becomes a willingness-to-pay measure. In this context, under differentiability, the marginal benefit of food $\partial B/\partial x$ is the marginal willingness-to-pay for one more unit of x. Under competitive markets, note that the marginal benefit is equal to the market price. This provides a measure of the consumer price of food:

$$p^d(x, y, U) = \partial B(x, y, U)/\partial x. \tag{2}$$

Eq. (2) is the price-dependent Hicksian demand for food. When the utility function $U(x, y)$ is quasi-concave, the benefit function is concave (Luenberger, 1996). Then, the price-dependent Hicksian demand $p^d(x, \cdot)$ in (2) is downward-sloping: the consumer's marginal benefit of food $p^d(x, \cdot)$ declines as food consumption x increases: $\frac{\partial p^d}{\partial x} \leqslant 0$. In addition, the slope of the price-dependent Hicksian demand $p^d(x, \cdot)$ and the slope of the quantity-dependent Hicksian demand $x^c(p, \cdot)$ are closely related. When prices are normalized so that the price of non-food is equal to 1, they satisfy

$$\frac{\partial p^d(x, \cdot)}{\partial x} \frac{\partial x^c(p, \cdot)}{\partial p} = 1. \tag{3}$$

Eq. (3) states the intuitive result that $p^d(x, \cdot)$ and $x^c(p, \cdot)$ are inverse functions of each other. A formal proof is given in Luenberger (1996): Eq. (3) follows directly from Luenberger's Proposition 5 (Luenberger, 1996, p. 450) when benefit is measured in terms of units of non-food and the price of non-food is 1.

Eqs. (2) and (3) are key duality results. They establish important linkages between demand behavior and the benefit of food. We will use these linkages below to obtain empirical estimates of the benefit of food and to evaluate the cost of food insecurity.

As noted above, food is a necessary consumption good for humans. Let x_S denote the minimum food consumption that is necessary to sustain human life. Interpreting x_s as the starvation threshold, it follows that any food consumption in the range $[0, x_s]$ implies starvation and death. But willingness-to-pay measures are relevant only when individuals are alive. This has one important implication: the individual food benefit measure $B_i(x, \cdot)$ in (1) applies only when $x \geqslant x_s$. On that basis, when $x \geqslant x_s$, combining (1) and (2), we can measure the individual benefit of food as

$$\begin{aligned} B(x, \cdot) &= \int_{x_s}^{x} \frac{\partial B(z, \cdot)}{\partial z} dz \\ &= \int_{x_s}^{x} p^d(z, \cdot) dz \end{aligned} \tag{4}$$

Using (3), Eq. (4) provides a basis to evaluate the individual benefit of food $B(x, \cdot)$. This is illustrated in Fig. 1, where $B(x, \cdot)$ is given by the area below the price-dependent Hicksian demand (measuring marginal benefit) and between the starvation point x_s and food consumption x. Note that the Hicksian demand shown in Fig. 1 does not exist below the starvation threshold x_s. From Eq. (4), $B(x, \cdot)$ is equal to areas {A + D} in Fig. 1, with areas {B + D} measuring food consumption expenditure.

The starvation threshold x_s in Eq. (4) has strong implications for the evaluation of food and food security. To illustrate, consider situations where the purchasing power for food (I/p) is very low and less than the starvation threshold. In such situations, $(I/p) < x_s$ and the consumer cannot pay for a diet that would sustain life. This shows that starvation would arise in situations where consumers are very poor (income I being low) and/or where the price of food p is sufficiently high (Sen, 1981). This is illustrated in Fig. 1. If the price of food p exceeds the threshold price p_S in Fig. 1, the consumer does not have enough resources/income to avoid being the starvation zone $[0, x_s]$. In this context, the consumer's willingness-to-pay is constrained to be 0 (by a lack of ability to pay). Avoiding starvation can then be done by lowering the price of food p and/or by increasing consumer income I (which would shift the demand curve for food to the right in Fig. 1). This identifies the role played by both pricing policy and income distribution policy in the management of food security issues.

In a step toward empirical analysis, we consider the case where the starvation point in (4) is $x_s = \$300$ per person per year. Assuming an associated food budget share $W = 0.9$, this would correspond to a per capita income of \$333 per year or \$0.91 per day. Note that this is lower than the international poverty line of \$1.25 per person per day proposed by Ravallion et al. (2009).[7]

We proceed evaluating the benefit of food $B(x, \cdot)$ in (4) under three scenarios denoted by Sc_1, Sc_2 and Sc_3. On a per-person and per-year basis, we let food expenditure (px) be \$1000 under scenario Sc_1, \$1500 under scenario Sc_2, and \$2000 under scenario Sc_3. Note that all three scenarios involve food expenditures that are higher than the starvation point ($x_s = \$300$ per person per year). As discussed below, we interpret scenario Sc_1 as representing a situation of high food insecurity, scenario Sc_2 a situation of mild food insecurity, and scenario Sc_3 a situation of food security.

Under scenario Sc_3, a food expenditure of \$2000 per person per year corresponds to the cost of a nutritious diet as evaluated by USDA under a thrifty plan for a family of four (USDA, 2015). Thus, scenario Sc_3 reflects food consumption patterns that can support a nutritious diet. This motivates our interpretation of scenario Sc_3 as representing a situation of food security. Note that scenarios Sc_1 and Sc_2 involve lower food expenditures than scenario Sc_3. As such, scenarios Sc_1 and Sc_2 exemplify situations exhibiting some form of undernutrition (especially scenario Sc_1). Given that food expenditure under Sc_1 (\$1000) is half of the food-secure scenario Sc_3 (\$2000), this motivates our interpretation of scenario Sc_1 as representing a situation of high food insecurity. And being located between scenarios Sc_1 and Sc_3, we interpret scenario Sc_2 as representing mild food insecurity.

To offer additional interpretations, assume that the food budget share W is 0.34 under scenario Sc_2 (in a way consistent with A1

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[7] Note that, starting in October 2015, the World bank has updated the international poverty line to \$1.90 per person per day.

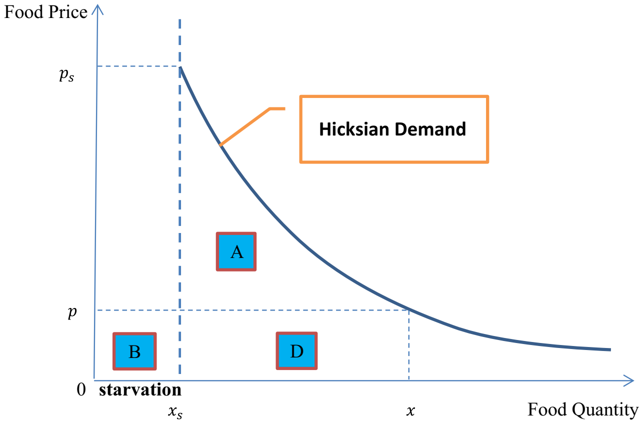

Fig. 1. Per Capita Hicksian food demand.

and Table 1). It follows that per capita income would be \$4412 per year (or \$12 per day) under Sc_2. In their study of the world income distribution, Hellebrandt and Mauro (2015) report that the distribution of annual per capita income in 2013 has a median of \$2010 and a mean of \$5374 (expressed in 2011 US dollars evaluated using purchasing-power-parity prices).[8] Thus, with \$4412 being between the median and the mean of the world income distribution, scenario Sc_2 represents a fairly typical consumer in the world. We will argue below that Sc_2 has a more specific and useful interpretation: scenario Sc_2 corresponds to a representative consumer in the sense that its value of food approximates the current per capita value of food in the world.

From Table 1 and condition A3, consider the case where the Hicksian demand for food has constant price elasticity $E_p^c = -0.37$. Then, using (3) and (4), the individual benefit of food x is

$$\begin{aligned} B(x,y,U) &= \int_{x_s}^{x} \alpha(y,U) z^{\frac{1}{E_p^*}} dz \\ &= \alpha(y,U) \frac{E_p^c}{1+E_p^c} \left[x^{1+\frac{1}{E_p^*}} - x_s^{1+\frac{1}{E_p^*}} \right], \end{aligned} \tag{4'}$$

where $\alpha(y,U)$ is a parameter that varies with consumer welfare.[9] Estimates of B in (4′) are reported in Table 2 under the three scenarios just discussed. On an annual basis, the per capita value of food B is equal to \$3975, \$12,768 and \$28,526 under scenarios Sc_1, Sc_2 and Sc_3, respectively. This reflects a strong positive relationship between individual standard of living and the willingness to pay for food.

Next, consider the case where B_i in (4) or (4′) denotes the benefit of food for the i^{th} individual. As showed by Luenberger (1995, 1996), the benefit function has nice aggregation properties: aggregate benefit can be obtained by just adding individual benefits. Let pop denote the world population. Then, the aggregate (gross) benefit of food is

$$B_w = \sum_{i=1}^{pop} B_i, \tag{5a}$$

stating that world gross benefit of food B_w is equal to the sum of individual benefits across all persons. Eq. (5a) allows for heterogeneity in benefits across individuals, reflecting that the distribution of income and purchasing power affects world benefit B_w.

Table 2
Welfare evaluation of the food system.[a]

	Scenario Sc_1: high food insecurity	Scenario Sc_2: mild food insecurity	Scenario Sc_3: food security
Individual benefit (\$)			
$B = \int_{x_s}^{x} p^d(z,\cdot)dz$	3975	12,768	28,526
World benefit (\$ trillion)			
Gross benefit $B_w = pop \times B$	27.824	89.374	199.680
Cost of production $C = \int_0^X p^s(z)dz$	0.636	0.954	1.273
Net benefit $NB = B_w - C$	27.187	88.419	198.408
Gross market value $GMV = p \times X$	7.000	10.500	14.000
Ratio GMV/B_w	0.251	0.117	0.070
Net market value $NMV = GMV - C$	6.363	9.545	12.727

[a] The evaluation assumes $E_p^c = -0.37$, $E^s = 0.10$, minimum food consumption expenditure x_s = \$300 per capita, and world population pop = 7 billion people. The Sc scenarios involve per capita food expenditure of \$1000 under scenario Sc_1, of \$1500 under scenario Sc_2, and of \$2000 under scenario Sc_3.

To evaluate these distribution effects, we combined the world distribution of per capita income reported in Lakner and Milanovic (2013) and estimates of food Engel curves from Gao (2012) to obtain the distribution of per capita food expenditure in the world in 2011. And after adjustments to 2011 prices, we used Eq. (4′) to simulate the world distribution function of individual food benefits B_i. The results are presented in Fig. 3, showing the world distribution function of income and the world distribution function of individual food benefit. The two distribution functions are skewed. Like income, food benefits are unevenly distributed, with many people receiving low food benefit and few receiving relatively large food benefits. As expected, this reflects that income is a major determinant of food benefit. Yet, the two distribution functions in Fig. 3 differ in significant ways. This is illustrated in Fig. 4. Fig. 4 reports how income relates to relative food value as measured by two key variables: food budget share, and the ratio (food benefit/income). In a way consistent with Engel's law, Fig. 4 shows that the food budget share declines monotonically with income. But the ratio (food benefit/income) exhibits more complex patterns. Fig. 4 reveals that the relationship between this ratio and income has an inverted U-shape. This ratio starts at 0 under extreme poverty; it increases with income to reach a maximum of 4.4 for an individual income of \$13,000; and it then declines slowly as income rises. This pattern documents important distributional aspects of food benefit. Under extreme poverty, food benefit is 0 as the consumer is so poor that he/she lacks the purchasing power to acquire subsistence food. This is the scenario discussed by Sen (1981) in his discussion of famine. It corresponds to situations where food benefit is severely constrained by very low purchasing power. But as individual income increases beyond extreme poverty, Fig. 4 shows that food benefit rises. First, it rises fast so as to increase the ratio (food benefit/income), up to an individual income of \$13,000. Around \$13,000, the largest average food benefit is obtained: \$4.4 of food benefit per \$1 of income. Beyond \$13,000 income, the ratio (food benefit/income) declines, meaning that food benefit continues to increase but at a slower rate than income. In such situations, Engel's law implies that most of the increase in income is not spent on food, with welfare improvements coming mostly from non-food consumption. Finally, Fig. 4 shows that the ratio (food benefit/income) is larger than 1 for a wide range of individual income, going from \$1500 to \$78,000. Thus, outside either extreme poverty or extreme wealth, food benefit tends to be larger than income. This documents important linkages between food, income and welfare.

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[8] The large difference between mean income and median income reflects the fact that the probability distribution of world income is asymmetric and heavily skewed to the right (e.g., Lakner and Milanovic, 2013; Hellebrandt and Mauro, 2015).

[9] For a given food price p, the parameter $\alpha(y,U)$ in (4′) can be obtained by solving $\frac{\partial B(x,\alpha(y,U))}{\partial x} = p$ and (px) = individual food expenditure for a given income level.

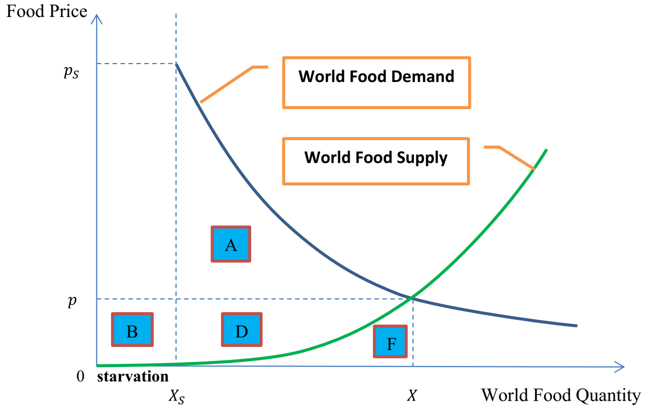

Fig. 2. World food supply and demand.

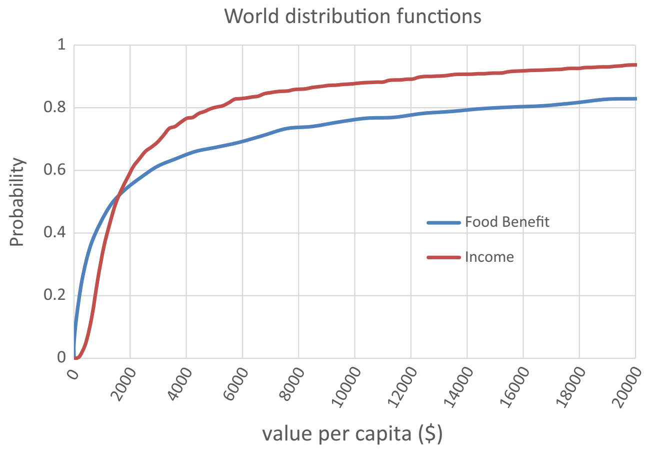

Fig. 3. World distribution functions of individual income and food benefit (evaluated in 2011).

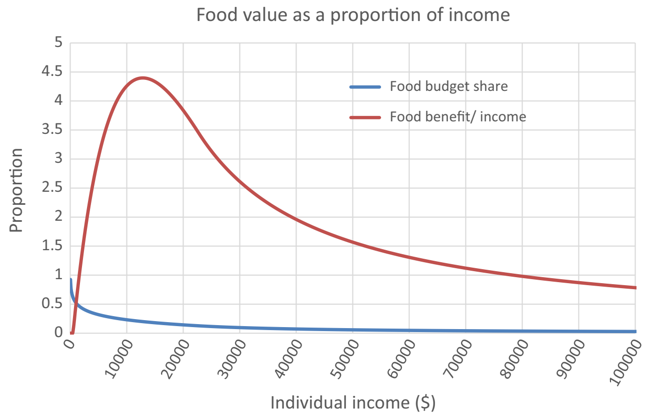

Fig. 4. Food value as a proportion of income.

From the above analysis, we can use (5a) to evaluate the world food benefit B_w in 2011. And assuming a world population of 7 billion people, we can estimate the per-capita food benefit B_w/pop. This estimate was found to be \$12,567, which is very close to the estimated individual benefit obtained under scenario Sc_2 (\$12,768). This shows that our scenario Sc_2 corresponds to a "representative consumer" in the sense that his/her valuation of food approximates the world food benefit per capita. In this case, we have a simple way to evaluate world food benefit. Indeed, when B is the food benefit associated with a representative consumer, then the aggregate world benefit of food in (5a) takes the simpler form

$$B_w = pop \times B. \tag{5b}$$

Below, we will make extensive use of Eq. (5b). It should be kept in mind that (5b) is valid only when the individual benefit B applies to a "representative consumer". As just discussed, this appears to be a good assumption when applied to scenario Sc_2. Yet, we will also apply (5b) to other scenarios for two reasons. First, relying on (5b) will provide a convenient basis to conduct some sensitivity analyses on the factors affecting the aggregate valuation of food. Second, using Eq. (5b) (instead of (5a)) will greatly simplify our empirical investigation. In particular, using Eq. (5a) requires information about the distribution of food benefits across individuals, information that is typically not readily available. On that basis, our analysis of aggregate benefit proceeds based on the measurement given in Eq. (5b).

Using (5b), Table 2 reports estimates of the aggregate benefit of food under the three scenarios discussed above, assuming a world population $pop = 7$ billion people. From Table 2, the world gross benefit of food B_w is \$27.827 trillion, \$89.284 trillion, and \$199,680 trillion under scenarios Sc_1, Sc_2 and Sc_3, respectively. These estimates show a strong positive relationship between standard of living and willingness to pay for food.

Next, we evaluate the cost of food production. Let $p^s(X)$ denote the marginal cost of producing food, X being the quantity of food produced in the world. Under competitive markets, note that the marginal cost $p^s(X)$ is also the price-dependent supply function, with $\partial \ln(p^s(X))/\partial \ln(X) = 1/E^s$ where $E^s = \partial \ln(X^*(p))/\partial \ln(p)$ is the price elasticity of world food supply. Then, the cost of world food production is

$$C = \int_0^X p^s(z)dz. \tag{6}$$

Using A4, consider the case where the price elasticity of world food supply is constant and satisfies $E^s = 0.10$. Then, Eq. (6) becomes

$$\begin{aligned} C &= \int_0^X \beta z^{\frac{1}{E^s}} dz \\ &= \beta \frac{E^s}{1+E^s} X^{1+\frac{1}{E^s}}, \end{aligned} \tag{6$'$}$$

where β is a constant.[10] Eq. (6′) provides a basis to evaluate the cost of food production in the world.

Next, define the world net benefit of food NB to be equal to the aggregate gross benefit B_w net of the cost of production C:

$$NB = B_w - C. \tag{7}$$

Consider the world market for food. Under market equilibrium (where aggregate supply equals aggregate demand), the world market for food is illustrated in Fig. 2. In Fig. 2, the cost of food production is given by area {F}. Estimates of the cost of food C and of the net benefit of food NB for the world are presented in Table 2 under our three scenarios. The cost of food C is \$0.636 trillion, \$0.954 trillion, and \$1.273 trillion under scenarios Sc_1, Sc_2 and Sc_3, respectively. And the corresponding world net benefits of food NB are \$27.187 trillion, \$89.419 trillion, and \$198,408 trillion. Note that the aggregate benefit B_w is much larger than the cost of food C. This reflects the fact that both the marginal benefit and the marginal cost functions are highly price-inelastic.

Economic efficiency is attained when aggregate net benefit NB

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[10] For a given food price p, the parameter β in (6′) can be obtained by solving $\frac{\partial C(X)}{\partial X} = p$.

in (7) is maximized (e.g., Luenberger, 1995, p. 193–194). This gives the standard result that, under efficiency, marginal benefit equals marginal cost. This result applies under general conditions. It applies in market economies where marginal benefit represents consumer demand and marginal cost is the supply function at the aggregate. And it applies in the presence of transaction costs and externalities (Chavas, 2015). As such our approach provides a useful framework to evaluate economic efficiency in the food sector. This includes assessing the welfare effects of food policy and the efficient management of food security issues.

In the context of the world food system, the gross market value of food is $GMV = pX$, where X is world food quantity. The corresponding net market value of food NVM is $NMV = GMV - C$, i.e. as the gross market value net of the cost of production. NVM can be interpreted as the return to the fixed factors (including land and agro-ecosystem services). This is illustrated in Fig. 2 where GMV is given by the areas {B + D + F} and NMV is given by the areas {B + D}. Table 2 reports the gross market value of food GMV and the net market value NMV under our three scenarios. The gross market value GMV is \$7 trillion, \$10.5 trillion and \$14 trillion under scenarios Sc_1, Sc_2 and Sc_3, respectively. And the corresponding net market values NMV are \$6.363 trillion, \$9.545 trillion and \$12.7127 trillion. Again, the cost of food C is relatively small compared to its aggregate gross market value GMV, reflecting the fact that marginal cost of food is highly price-inelastic. This implies that the net market values of food NVM are relatively large, indicating large returns to the fixed factors, including land and agro-ecosystem services.

From Table 2, the ratio GMV/B_w varies from 0.251 under scenario Sc_1, to 0.117 under scenario Sc_2, to 0.070 under scenario Sc_3. This shows that the consumer benefit from food B_w is much larger than its market value GMV. This is because food demand is highly price-inelastic, generating large "consumer surplus". Interestingly, moving from scenario Sc_1 (representing high food insecurity) to scenario Sc_3 (food security), the ratio GMV/B_w decreases (from 0.251 to 0.070) while gross benefit B_w rises sharply (from \$27.8 trillion to \$199.7 trillion) and GMV doubles (from \$7 trillion to \$14 trillion). This shows that, while the consumer surplus for food is large, the willingness-to-pay for food B_w increases faster than its market value GMV as the standard of living rises and food security improves. This reflects that the willingness-to-pay for food is constrained by consumers' ability-to-pay under food insecurity and that such constraints ease under food security.

Our analysis has important welfare implications. As noted above, willingness-to-pay becomes meaningless in the starvation zone $[0, x_s]$. More generally, the possibility of facing starvation means that ability-to-pay issues affect willingness-to-pay measures. As illustrated in Table 2, willingness-to-pay declines sharply when individuals face greater food insecurity (e.g., moving from scenario Sc_3 to scenario Sc_1). This occurs because ability-to-pay for food also deteriorates. Indeed, both willingness-to-pay and ability-to-pay tend toward 0 when the food purchasing power (I/p) declines toward the starvation threshold x_s. In such situations, willingness-to-pay measures and thus markets would fail to provide proper guidance for efficient allocations. Then there is an important role for non-market mechanisms (including food policy and income distribution policy) in the management of food insecurity issues.

4. Food security under uncertainty

The above analysis of the value of food was presented assuming no uncertainty. Situations of food insecurity arise when an individual or a household has limited or uncertain access to adequate food. Analyzing the economics of food insecurity requires evaluating the role of uncertainty. A significant source of uncertainty comes from unpredictable factors that affect the food supply, including the adverse effects of weather shocks and diseases on agricultural production. Such issues have become even more important given current concerns about the effects of climate change on the world food system (Nelson, 2014). Other important factors include imperfections in food markets (e.g., the case of "food deserts" and their adverse effects on consumer access to food) and shocks affecting food purchasing power. Indeed, defining food purchasing power as I/p, any unpredictable change in income I and/or in food price p affects the consumer ability to obtain food. This section examines the valuation of food security in situations where access to food is uncertain.

Consider the case of a consumer facing uncertain food consumption represented by the random variable $\tilde{x}$ that has a given probability distribution. Let the mean of $\tilde{x}$ be $\bar{x} = E(\tilde{x})$, where E is the expectation operator. Assume that consumer welfare is measured by expected benefit $E[B(\tilde{x}, \cdot)]$ where B is the benefit function defined in (1). Define the cost of food insecurity R. as the consumer willingness-to-pay to eliminate risk by replacing the random variable $\tilde{x}$ by its mean $\bar{x}$. Then, evaluated at a point where the price of food is equal to 1, the cost of food insecurity is the sure amount R satisfying

$$E[B(\tilde{x}, \cdot)] = B[E(\tilde{x}) - R, \cdot]. \tag{8}$$

When $p = 1$, R in (8) can be interpreted as a monetary measure of the cost of food insecurity.[11] By definition, the consumer is said to exhibit $\left\{\begin{matrix} \text{risk aversion} \\ \text{risk neutrality} \\ \text{risk loving} \end{matrix}\right\}$ with respect to food insecurity when $R \left\{\begin{matrix} > \\ = \\ < \end{matrix}\right\} 0$. From Eq. (8), let $CE \equiv (E(\tilde{x}) - R)$ be the certainty equivalent defined as expected food consumption $E(\tilde{x})$ net of the cost of food insecurity R. Thus, for a given $E(\tilde{x})$, aversion to food insecurity $(R > 0)$ implies a decline in the certainty equivalent CE and a decline in expected food benefit $E[B(\tilde{x}, \cdot)]$. This is a scenario where food insecurity has negative effects on expected food benefit.

Eqs. (4) and (8) give a basis to evaluate R as the welfare cost of food insecurity. Let $r(x) \equiv -\frac{\partial ln\left(\frac{\partial B(x,\cdot)}{\partial x}\right)}{\partial \ln(x)}$ be the Arrow-Pratt relative risk aversion coefficient applied to the benefit function.[12] From (2) and (3), it follows that $r(x) = -\frac{1}{E_p^c}$. This is a key result: the relative risk aversion coefficient $r(x)$ is equal to minus the inverse of the price elasticity of Hicksian demand E_p^c.

This result has important implications for our analysis of food security. First, having $E_p^c < 0$ (e.g., as reported in Table 1) implies that consumers are averse to food insecurity. This follows from Pratt (1964) as $r(x) > 0$ for all x implies that $R > 0$. This result is expected to hold under general conditions (as a quasi-concave utility function implies a concave benefit function and thus risk aversion; see Luenberger (1995)). Thus, our analysis indicates that aversion to food insecurity is a prevalent characteristic of human behavior. Second, the constancy of E_p^c (as indicated in condition

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[11] In a given situation, we can obtain $p = 1$ simply by rescaling the measure of food quantity such that one unit of food is defined to have a unit price in the market. This is implemented in the evaluation of the cost of food insecurity presented in Table 3 below.

[12] Note that $r(x) = -\frac{\partial ln\left(\frac{\partial B(x,\cdot)}{\partial x}\right)}{\partial \ln(x)}$ is the elasticity of the marginal benefit of food with respect to food x. A related measure has appeared in the literature: the elasticity of the marginal utility of income with respect to income (or its reciprocal called the Frisch coefficient) (e.g., Deaton and Muellbauer, 1980, p. 141). Yet, the two measures differ: the elasticity $r(x) = -\frac{\partial ln\left(\frac{\partial B(x,\cdot)}{\partial x}\right)}{\partial \ln(x)}$ applies only to food (and not to income).

A3) implies constant relative risk aversion (CRRA), where $r(x)$ is a constant that does not vary with x. Third, the estimate $E_p^c = -0.37$ (reported above) implies that the consumer exhibits CRRA preferences with a relative risk aversion coefficient $r = 2.70$. Gollier (2001, p. 31) has argued that the relative risk aversion coefficient typically varies between 1 and 4. Thus, our estimate of 2.7 provides a useful characterization of consumer risk preferences with respect to food insecurity: the degree of aversion to food insecurity is in the range between “moderate” and “high”.[13] Finally, when the benefit function is given by (4′), then solving Eq. (8) for Ryields

$$R = E(\tilde{x}) - \left[E[B(\tilde{x},\cdot)]\frac{1+E_p^c}{\alpha(\cdot)E_p^c} + x_s^{\,1+\frac{1}{E_p^*}}\right]^{\frac{E_p^c}{1+E_p^c}}, \tag{8′}$$

which is an explicit equation for the cost of food insecurity.

It is useful to compare our results with those obtained by Turnovsky et al. (1980). First, there is a crucial difference: our analysis examines the case of quantity uncertainty, while Turnovsky et al. (1980) study the case of price uncertainty. Second, Turnovsky et al. (1980) find that the welfare effects of price uncertainty are ambiguous.[14] This contrasts with our result showing the prevalence of aversion to food insecurity. This is important from a policy viewpoint. Indeed, the cost of food insecurity being unambiguously positive means that any policy that reduces consumer exposure to food insecurity can potentially increase consumer welfare. The magnitude of such welfare effects are discussed below.

While (8)–(8′) provide a basis to evaluate the individual cost of food insecurity, the analysis can also be applied at the aggregate level. Letting R_i be the cost of food insecurity for the i-th individual and pop. be the world population, the aggregate cost of food insecurity is

$$R_w = \sum_{i=1}^{pop} R_i. \tag{9a}$$

Eq. (9a) states that world cost of food insecurity is the sum of the individual R_i's across all persons. It allows for individual heterogeneity (e.g., reflecting differences in income and purchasing power across individuals). As such, Eq. (9a) shows how the distribution of income and of purchasing power can affect the world cost R_w.

As discussed above, under aversion to food insecurity, having the i-th consumer exposed to food insecurity means that $R_i > 0$, implying a reduction in expected benefit. Associating efficient allocations with the maximization of aggregate benefit, this indicates that an efficient management of food security would try to minimize the aggregate cost of risk R_w in (9a). This can be done by reducing the exposure to food security risk for all individuals. More specific ways of achieving this goal include: (1) increasing world food supply, (2) increasing consumer food purchasing power, and (3) improving access to food. Over the last few decades, the pace of agricultural innovations has been fast enough to match the growing world population (e.g., Fuglie, 2008). As a result, technological progress has allowed food production to increase at a faster rate than population growth, generating improvements in world food security (Leathers and Foster, 2009; FAO, 2015). Hopefully, this trend will continue in the future. But this will require sustainable management and significant investments in agricultural R&D. Currently, there is enough food to feed the world population. It means that food security issues have become more closely related to the distribution of income and food purchasing power among individuals/households.

In situations where the cost of food insecurity R_i varies across individuals, it is appropriate to focus attention on reducing the cost of risk for individuals having a large R_i. This can be done by increasing the quantity of food available to these individuals through markets, through income redistribution policies and/or through food pricing policies. Markets can help by transferring food over time (through storage), across space (through trade from food-surplus regions to food-deficit regions) and/or across states of nature (through insurance). But as noted above, markets can be effective in reducing food insecurity only in situations where food-insecure individuals have sufficient income and food purchasing power.

Policies redistributing food purchasing power can also help. These policies can take various forms, going from reducing the cost of food for the poor (e.g., through food stamps), to increasing income of poor households (through economic development and/or through income transfers policies), and to redistributing food toward food-insecure individuals (e.g., through food aid). Such policies can help but only in situations where aggregate food supply is sufficient so that reducing food insecurity for all people is feasible. In this context, efficient policies would target the individuals facing a large cost of food insecurity R_i and/or exhibiting low food-purchasing power.

Note that the empirical assessment of (9a) requires information about the distribution of risk exposure across individuals. Such information is often difficult to obtain. Eq. (9a) takes a simpler form if we are willing to assume the existence of a representative consumer. Indeed, if a representative consumer faces a cost of food insecurity R, then the aggregate welfare cost of food insecurity in (9a) reduces to

$$R_w = pop \times R, \tag{9b}$$

where pop denotes the world population. Eq. (9b) is applicable to the case of a “representative consumer”, i.e. to a consumer having a cost of food insecurity R equal to the aggregate cost per capita (R_w/pop). We will rely on Eq. (9b) as a basis to obtain some estimates of the aggregate cost of food insecurity under alternative scenarios (see below).

We illustrate next how the above information can be used to conduct an empirical evaluation of the economic value of food security. We consider two sets of risky situations, denoted here by $\mathrm{Sr}_1(\mathrm{e})$ and $\mathrm{Sr}_2(\mathrm{e})$. For a given $e > 0$, the first set of risk scenarios $\mathrm{Sr}_1(\mathrm{e})$ involves the random variable $\tilde{x}_1(e)$ that can take two values $(\bar{x} - e)$ and $(\bar{x} + e)$, each with probability 0.5. The second set of risk scenarios $\mathrm{Sr}_2(\mathrm{e})$ involves the random variable $\tilde{x}_2(e)$ that can take the value $(\bar{x} - 2e)$ with probability 0.2 and the value $(\bar{x} + e/2)$ with probability 0.8. Note that $\tilde{x}_1(e)$ and $\tilde{x}_2(e)$ have the same mean $E[\tilde{x}_1(e)] = E[\tilde{x}_2(e)] = \bar{x}$. And for a given $e > 0$, they have the same variance $Var[\tilde{x}_1(e)] = Var[\tilde{x}_2(e)] = \mathrm{e}^2$. This shows that increasing e generates a mean-preserving increase in the variance of $\tilde{x}_1(e)$ and $\tilde{x}_2(e)$. But $\tilde{x}_1(e)$ and $\tilde{x}_2(e)$ differ in their exposure to “downside risk”: while the probability of $\tilde{x}_1(e)$ is symmetric around the mean $\bar{x}$, the probability of $\tilde{x}_2(e)$ is asymmetric and involves a greater exposure to downside risk. As such, a move from scenario Sr_1 to Sr_2 represents a mean-variance-preserving increase in exposure to downside risk.

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[13] As noted in footnote 5, our estimate of the Hicksian demand elasticity $E_p^c = -0.37$ is a little more elastic than the average estimate of -0.27 reported in Gao (2012, p. 40). Given $r = -1/E_p^c$ as coefficient of relative risk aversion to food insecurity, switching to Gao's estimate would increase the coefficient of relative risk aversion r from 2.70 to 3.70. This would make the cost of insecurity a little higher than the ones reported below.

[14] Turnovsky et al. (1980, p. 143–144) find that the benefit from price stabilization depend on the elasticity of demand, the budget share and a coefficient of risk aversion. In general, such benefit can be either positive or negative. In contrast with our results, Turnovsky et al. (1980, p. 143) argue that the consumer benefit from food price stabilization may be negative, a result obtained earlier by Waugh (1944).

Table 3
Welfare cost of food insecurity.[a]

		Individual cost ($) R		Relative individual cost (%) $100 \times R/E(p\tilde{x})$		World cost ($ billion) R_w	
Shock e	Scenarios	$\mathrm{Sr}_1(e)$	$\mathrm{Sr}_2(e)$	$\mathrm{Sr}_1(e)$	$\mathrm{Sr}_2(e)$	$\mathrm{Sr}_1(e)$	$\mathrm{Sr}_2(e)$
$e = 15$ (1% shock)	Sc_1	0.30	3.84	0.030	0.38	2.12	26.89
	Sc_2	0.20	3.76	0.013	0.25	1.42	26.31
	Sc_3	0.15	3.72	0.008	0.18	1.06	26.03
$e = 75$ (5% shock)	Sc_1	7.58	24.82	0.76	2.48	53.10	173.78
	Sc_2	5.06	22.32	0.34	1.49	35.44	156.26
	Sc_3	3.80	21.16	0.19	1.06	26.59	148.14
$e = 150$ (10% shock)	Sc_1	30.15	68.21	3.01	6.82	211.06	477.48
	Sc_2	20.19	55.19	1.34	3.68	141.36	386.36
	Sc_3	15.17	49.65	0.76	2.48	106.19	347.56
$e = 300$ (20% shock)	Sc_1	117.68	261.71	11.77	26.17	823.75	1,831.96
	Sc_2	79.88	168.92	5.32	11.26	559.20	1,182.44
	Sc_3	60.30	136.42	3.01	6.82	422.12	954.97

[a] The evaluation assumes $E_p^c = -0.37$, minimum food consumption expenditure x_s = $300 per capita, and world population $pop = 7$ billion people. The Sc scenarios involve per capita food expenditure of $1000 under scenario Sc_1, of $1500 under scenario Sc_2, and of $2000 under scenario Sc_3. For a given e, the Sr scenarios involve the random variable $\tilde{x}_1(e)$ under scenario $\mathrm{Sr}_1(e)$, and the random variable $\tilde{x}_2(e)$ under scenario $\mathrm{Sr}_2(e)$ (where $\tilde{x}_1(e)$ and $\tilde{x}_2(e)$ are defined in the text). An increase in e gives a mean-preserving increase in the variance of $\tilde{x}_1(e)$ and $\tilde{x}_2(e)$.

Our analysis examines food insecurity under risk scenarios Sr_1(e) and Sr_2(e), and under four shocks: $e = 15$, 75, 150 and 300. These shocks correspond respectively to 1%, 5%, 10% and 20% shocks on food consumption under scenario Sc_2 (with food consumption per capita of $1500).

Estimates of the cost of risk R are presented in Table 3 under the selected scenarios. Table 3 also reports the relative cost of risk as measured by $[100 \times R/E(p \cdot \tilde{x})]$, reflecting the cost of risk as a percentage of expected food expenditure. Finally, using (9b), Table 3 reports the cost of risk at the world level (in $ billion), assuming a world population of 7 billion people.

First, consider scenarios Sc_2 (the case of a representative consumer) and Sr_1(e) (reflecting symmetric shocks). The individual willingness-to-pay to eliminate food insecurity R_i rises from $0.20 when e = 15 (a 1% shock), to $5.06 when e = 75 (a 5% shock), to $20.19 when e = 150 (a 10% shock), and to $79.88 when e = 300 (a 20% shock). As expected, the cost of risk increases with greater risk exposure (reflected by a higher e and a higher variance). The associated relative cost of risk $[100 \times R_i/E(p \cdot \tilde{x})]$ rises from 0.013% of food expenditures when e = 15, to 5.32% when e = 300. And the world cost of risk increases from $1.42 billion when e = 15, to $559.20 billion when e = 300.

Comparing the cost of risk under Sc_2 versus Sc_1 (lower food consumption) or Sc3 (higher food consumption) is of interest. Table 3 shows that R decreases monotonically from SC_1 to SC_2 to SC_3. This reflects that CRRA risk preferences exhibit Decreasing Absolute Risk Aversion (DARA), where increases in expected consumption reduce concerns about risk exposure (Pratt, 1964). This implies that the cost of risk R declines with $E(\tilde{x})$. Similar patterns apply to the world cost of food insecurity reported in Table 3.

Finally, Table 3 shows that switching from scenarios Sr_1(e) (symmetric risk) to scenarios Sr_2(e) (asymmetric risk with greater exposure to downside risk, holding mean and variance constant) has a large positive impact on the cost of food insecurity. For example, under Sc_2, going from scenarios Sr_1(e) to Sr_2(e), Table 3 shows that R increases from $5.06 to $22.32 when e = 75, and from $79.88 to $168.92 when e = 300. The associated impacts on the relative cost of risk $[100 \times R_i/E(p\tilde{x})]$ are increases from 0.34% to 1.49% of food expenditure when e = 75, and from 5.32% to 11.26% when e = 300. This shows that a large part of the cost of food insecurity comes from exposure to downside risk. Using (9b), these qualitative findings also apply at the world level. For example, under Sc_2, going from scenarios Sr_1(e) to Sr_2(e) gives an increase in the world cost of food insecurity from $35 billion to $156 billion when e = 75, and from $559 billion to $1182 billion when e = 300. These estimates indicate the potentially large cost of food insecurity in the presence of significant adverse shocks to the world food system. This stresses the importance of economic and food policies that attempt to reduce the cost of food insecurity.

5. Concluding remarks

The paper has evaluated the value of food and the cost of food insecurity. This is relevant for food policy to the extent that reducing food insecurity for all individuals is seen as an important policy goal (FAO, 2015). Achieving this goal can be done in several ways: by increasing world food supply, by improving access to food, and by increasing consumer food purchasing power. Currently, there is enough food to feed the world population. This has focused the food policy debate on access to food and on the linkages between food security and the distribution of food purchasing power. Increasing individual access to food can be done through markets, through income redistribution policies and/or through food policies. And redistributing food purchasing power can involve reducing the cost of food for the poor (e.g., through food stamps), increasing income of poor households (through economic development and/or through income transfers policies), and redistributing food toward food-insecure individuals (e.g., through food aid). But evaluating these programs has been challenging. This paper has taken a step toward addressing these challenges by exploring the economics and welfare evaluation of food and food security. In the process, it has provided new and useful information to economists and policy analysts interested in the food sector and in the evaluation of food security policies.

The analysis builds on behavioral regularities of consumers and the role played by food purchasing power. It establishes linkages between food demand and the value of food, with implications for the aggregate value of food in the world. It finds that the aggregate net benefit of food is very large, with an estimated value $88 trillion. The analysis also evaluates the cost of food insecurity. The properties of food demand indicate that aversion to food insecurity is a prevalent characteristic of human behavior, with a coefficient of relative risk aversion equal to 2.7. This implies that the cost of food insecurity can be large, especially in situations of exposure to significant downside risk. Such findings stress the importance of economic and food policies that attempt to increase the value of food and/or to reduce the cost of food insecurity.

While the analysis provides a formal framework to evaluate the benefit of food and the cost of food insecurity, several issues remain unsettled and are in need of further research. First, data limitations often make evaluating the distributional effects of alternative food policies challenging. Making progress in this area will require improved data on food consumption collected at the individual/household level. Second, our analysis has been applied to food treated as an aggregate good. Extending the analysis to specific food items (e.g. cereals, fruits, vegetables) and to specific nutrients (e.g., macro nutrients, micro nutrients) would be useful. Third, the investigation of food security needs to examine also the role of food quality and food safety. Fourth, food and nutrition have implications for human welfare that can differ in the short run versus the long run (e.g., Strauss and Thomas, 1998; Arora, 2001; Taniguchi and Wang, 2003; Fogel, 2004; Chavas, 2013, 2016). There is a need to explore the longer term implications of food and nutrition. Investigating such issues appears to be good topics for future research.

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