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WORLD FOOD DEMAND

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Abstract

Food occupies a role of particular importance in the consumer's budget, especially in poor countries. This paper deals with special issues arising from modelling food consumption patterns in 138 countries, where per capita incomes differ by as much as a factor of 100. We explore various forms of the Engel curve, and emphasise the economic behaviour of the income elasticity and the [0, 1] domain of the budget share. Using a new functional form to allow for the substantial variation in prices across countries, we provide estimates of income and price elasticities in each country. Stress testing is also employed by considering the implications of extreme values of income.

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1. **Introduction**

There are great disparities in consumption patterns across countries. For example, the poorest countries devote more than one-half of total consumption to food, while in the most affluent this commodity absorbs less than 10 percent. The dominant economic difference among countries is that incomes vary substantially, with the ratio of income per capita in the richest country to that in the poorest of the order of 100. For example, according to the recently-published data from the International Comparison Program (hereafter, the ICP)[1], in 2005 GDP per capita of the US is more than $30,000 (international dollars), while that of the Democratic Republic of Congo is only about $132. In these cross-country data, we clearly observe that the more affluent have smaller food budget shares, which is evidence of Engel's law. In this paper, we introduce a new approach to model the consumption of food, the dominant commodity in most countries.[2] We explore alternative functional forms, emphasise their economic implications and apply our approach to 138 countries from ICP (2008).[3]

As food is a necessity (Engel's law), its income elasticity is less than one. But how should this elasticity vary with income? To address this issue, consider the linear Engel curve of the form: food expenditure $= \alpha + \beta \cdot M$, where $\alpha,\ \beta > 0$ are constants and M is income. The implied income elasticity is β/w, where w is the food budget share (that is, $w = \text{food expenditure}/M$). As w falls with income and as the slope coefficient β is a positive constant, the elasticity increases with income. Accordingly, the Engel curve implies that food becomes less of a necessity, or more of a luxury as the consumer becomes more affluent, which violates economic intuition (Theil 1983). When the food income elasticity is allowed to vary freely over countries, Lluch et al. (1977) found that this elasticity does indeed fall as income rises. For example, over the period 1955-1968, the average per capita income in the US was about 25 times that of Korea, while the food income elasticity was estimated to be 0.7 in Korea and 0.3 in the US.[4]

Although this rise in the income elasticity appears to be a fundamental flaw, the linear Engel curve is implied by the popular linear expenditure system (Stone 1954) and the Rotterdam demand model (Barten 1964, Theil 1965). An alternative model is Working's (1943), whereby the budget share is a linear function of the logarithm of income, $w = \alpha + \beta \cdot \log M$. Here the income elasticity takes the form $1 + \beta/w$, which decreases with income for necessities $(\beta < 0)$. While this model has plausible implications and has been popular in cross-country demand studies, it suffers from the defect that for large changes in income, the budget share ultimately becomes negative or larger than unity, which is

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[1] The data referred to here and used subsequently are from the International Comparison Program "Global Purchasing Power Parities and Real Expenditures", www.world bank.org, 2008, hereafter referred to as ICP (2008). For details, see the Appendix A1.

[2] For an early, influential study on food demand, see Tobin (1950). Tobin's work stimulated a number of subsequent papers including Anderson and Vahid (1997), Bearse et al. (1997), Chetty (1968), de Crombrugghe et al. (1997), van Driel et al. (1997), Izan (1980), Leamer (1997), Maddala (1971) and Song et al. (1997). For recent research on food demand, also see Huang (1988), Kastens and Brester (1996), LaFrance et al. (2002), Piggott (2003), Reed et al. (2005) Wang et al. (1997) and Yu et al. (2004).

[3] The literature on international comparisons of consumption patterns dealing with broad groups of commodities includes Chen (1999), Clements and Chen (1996), Clements and Selvanathan (1994), Clements and Theil (1979), Clements et al. (2006), Goldberger and Gamaletsos (1970), Houthakker (1957), Kravis et al. (1982, Chapter 9), Lluch and Powell (1975), Lluch et al. (1977), Pollak and Wales (1987), Regmi and Seale (2010), Seale and Regmi (2006), Selvanathan (1993), Selvanathan and Selvanathan (2003), Theil (1996), Theil and Clements (1987) and Theil et al. (1981, 1989). See also Neary (2004), who emphasises the cross-country measurement of real income.

[4] For further analysis, see Clements and Selvanathan (1994, Sec. 10).

logically impossible.[5] To deal with this problem, Rimmer and Powell (1992a, b, 1996) developed a new demand system based on implicitly additive preferences, named AIDADS.[6] Cranfield et al. (2002) showed that the AIDADS system outperforms a number of other functional forms. However, important parameters of AIDADS depend on the level of utility, which cannot be found explicitly in terms of the model's exogenous variables. An additional issue is that the iterative process to evaluate utility introduced by Rimmer and Powell seems to be quite complex.

In addition to our economic explorations of alternative Engel curves for food and the price sensitivity of its consumption, we provide evidence regarding the likely importance of the defect noted above with Working's model whereby the budget share can stray outside the [0, 1] interval. The structure of the paper is as follows. Section 2 investigates alternative food Engel curves, while Section 3 analyses the stochastic implications of the [0, 1] domain of the food share. Section 4 allows for the impact of international variation in prices using the differential approach to consumption theory. In Section 5, we introduce a novel way to study the seriousness of the [0, 1] domain problem by focusing on extreme values of income, which is a type of "stress testing". In that section we also present measures of the cross-country sensitivity of consumption to variations in income and prices. Concluding comments are contained in Section 6.

2. Alternative Engel Curves

In this section, we ignore price differences and explore alternative functional forms of the Engel curve for food using data for 138 countries from the ICP 2005 round. As total expenditure is expressed in term of domestic currency, purchasing power parity data on total expenditure is applied in cross-country comparison. These data are presented in Table 2.1.[7] To set the scene for these models, let p be the price of food, q be the corresponding quantity demanded per capita, so that pq is per capita expenditure on food. Define M as total real expenditure per capita (to be called "income" for short) and w as the proportion devoted to food, which is known as the "budget share". Clearly, $0 \leq w \leq 1$. According to Engel's law, the food budget share declines as income increases. The corresponding marginal concept is the marginal share, defined as $\theta = \partial(pq)/\partial M$, which answers the question: If income increases by $1, how much of this increase is spent on food? This θ must be less than 1 and is most likely to be positive (so that food is a normal good). The income elasticity of demand for food is $\eta = \partial(\log pq)/\partial(\log M) = \theta/w$. As $\eta = 1 + \partial(\log w)/\partial(\log M)$, Engel's law implies that $\eta < 1$.

[5] Working's model underlies the almost ideal demand system (AIDS) of Deaton and Muellbauer (1980). The violation of the [0, 1] constraint is the reason Deaton and Meullbauer have to include "almost" as part of the name. For examples of the use of Working's model in cross-country demand analysis, see Chen (1999), Clements and Theil (1979), Seale and Regmi (2006), Selvanathan (1993), Theil (1996), Theil and Clements (1987) and Theil et al. (1981, 1989).

[6] Additionally, Cooper and McLaren (1992) modified the cost function underlying AIDS to preserve regularity properties and obtained share equations satisfying the [0, 1] restriction. See also Fry et al. (1996) and Woodland (1979).

[7] According to the ICP (2008, p. 136), the commodity food includes "food products and nonalcoholic beverages purchased for consumption at home; and excludes food products and beverages sold for immediate consumption away from the home by hotels, restaurants, cafes, bars, kiosks, street vendors, automatic vending machines and so forth; cooked dishes prepared by restaurants for consumption off their premises; cooked dishes prepared by catering contractors, whether collected by the customer or delivered to the customer's home; and products sold specifically as pet foods."

Four Engel Curves

Working's model (1943) states that the budget shares are a linear function of the logarithm of income

$$w = \alpha + \beta \log M, \quad (2.1)$$

where α and β are parameters. The marginal share and income elasticity implied by Working's model is $\theta = w + \beta$ and $\eta = 1 + \beta/w$, as mentioned above, so that the difference between marginal and budget shares is a constant. Figure 2.1 is a scatter of the food share against income for the ICP countries, and it can be seen that there is indeed an approximate linear relation between w and $\log M$.[8] However, the obvious shortcoming of the model can also be seen: When the income increases substantially, the implied budget share becomes negative. One of the objectives of this paper is to analyse the seriousness of this shortcoming.

The **generalised Working's model** (Laitinen et al., 1983) involves a Box-Cox type transformation of income:

$$w = \alpha M^{\gamma} + \beta M^{(\gamma)}, \quad (2.2)$$

where $M^{(\gamma)} = (M^{\gamma} - 1)/\gamma$ and γ is the Box-Cox parameter. The implied marginal share is $\theta = (\gamma + 1)w + \beta$, and the income elasticity is $\eta = \beta/w + (\gamma + 1)$. Consider four special cases of this functional form, with each case corresponding to a particular value of the parameter γ:

1. When $\gamma \to 0$, $M^{\gamma} \to 1$ and $M^{(\gamma)} \to \log M$, then the model reduces to Working's model.
2. When $\gamma = -1$, the model becomes $w = (\alpha - \beta)M^{-1} + \beta$. This is a linear expenditure function, $pq = (\alpha - \beta) + \beta M$, where $\theta = \beta$ is a constant, and $\eta = \beta/w$.
3. When $\gamma = 1$, the model becomes $w = (\alpha + \beta)M - \beta$. This is a quadratic expenditure function $pq = (\alpha + \beta)M^2 - \beta M$, with marginal share $\theta = 2(\alpha + \beta)M - \beta$, and income elasticity $\eta = \beta/w + 2$.
4. When $\gamma = -2$, the model becomes $w = (\alpha - \beta')M^{-2} + \beta'$, where $\beta' = \beta/2$, and $pq = (\alpha - \beta')M^{-1} + \beta' M$, which is linear in income and its reciprocal. In this case, the marginal share is $\theta = -(\alpha - \beta')M^{-2} + \beta'$, and the income elasticity is $\eta = \beta/w - 1$.

While the generalised model is more flexible, it has the same shortcoming as Working's: the budget share may lie outside the [0, 1] interval.

To avoid unreasonable values of the budget share, consider the logistic function:

$$w = \frac{\alpha + \beta e^{M}}{1 + e^{M}}, \quad (2.3)$$

where α and β are parameters. This **logistic model** function ensures that the budget share behaves logistically, remaining always in the $[\beta, (\alpha + \beta)/2]$ interval for a necessity $(\text{when } \beta < \alpha)$ and

[8] Here and elsewhere, "income" is real total consumption expenditure per capita measured in international dollars.

$\left[(\alpha+\beta)/2,\ \beta\right]$ for a luxury $(\beta>\alpha)$. The marginal share and income elasticity are $\theta = w + k(\beta-\alpha)$ and $\eta = 1+(\beta-\alpha)k/w$, respectively, where $k = Me^M\big/\left(1+e^M\right)^2 > 0$. When income increases indefinitely, both the food budget share and marginal share go to β and thus η approaches to 1. On the other hand, w and θ approach $(\alpha+\beta)/2$ and η approaches to 1 when income decreases to zero. Accordingly, this model implies that the poorest and the richest have the same food income elasticity, which is a drawback.

Suppose, hypothetically, that income is understated by $\alpha>0$, so that $M+\alpha$ represents "true" income. Consider the food budget share as a reciprocal function of true income:

$$w = \frac{\beta}{M+\alpha}, \qquad (2.4)$$

where β is parameter. For w to lie in the [0, 1] interval, α and β should be positive, and $\beta-\alpha \le M$. If income is less than the difference of these two parameters, the budget share lies above 1. As will be seen in next subsection, empirically, $\beta \le \alpha$, which means any income level is higher than the difference $\beta-\alpha$. Combining equation (2.4) with $\eta = 1+\partial \log w/\partial \log M$, we obtain that the income elasticity is proportional to the reciprocal of true income, $\eta = \alpha/(M+\alpha)$, which falls from 1 to 0 as M increases. We shall call (2.4) the "**multiplicative variable elasticity**" (MVE) model.

Table 2.2 provides a convenient summary of the four models and their properties.

Application to 138 Countries

Estimates of the four models applied to the ICP (2008) data are given in the first four rows of Panel A of Table 2.3. Working's model and its generalisation both fit the data well with R-square values about 0.75; and as the estimate of the Box-Cox parameter γ is near 0, there is support for the simpler Working's model. For the logistic model, the fitted food budget share seems a bit too low for the low income countries. On the basis of R^2, the MVE model fits best, but there are not great differences across models. The remaining rows of Table 2.3 will be discussed subsequently.

Figure 2.2 presents the fitted budget share, marginal share, and income elasticity for the four models. As can be seen, in both Working's model and its generalisation, the marginal share and income elasticity become negative when per capita income exceeds \$22,000. Taken at face value, this means that in Denmark and higher-income countries, food is an inferior good. Actually, the data tell us these countries keep spending more on food (but not too much more), which points against inferiority. Rather than food being inferior, it is the model that is possibly inferior at high levels of income. The logistic model ensures that the budget share, marginal share, and income elasticity all lie in the [0, 1] domain, but the path of the income elasticity resembles a quadratic function of income (Panel C of Figure 2.2). As income rises from low levels, the elasticity falls from near unity and reaches a minimum around \$12,000; and thereafter the elasticity rises to end up again at near unity. As discussed above, the MVE model implies that the income elasticity falls with income and is always positive, properties that are illustrated in Panel D of Figure 2.2.

3. **Stochastic Properties**

Write the Engel curve functions discussed in previous section as:

$$w_c = f(M_c) + \varepsilon_c, \tag{3.1}$$

where the observed food budget share w_c is a function of income, M_c, in country c, $f(M_c)$ is one of the four alternative functional forms and ε_c is a zero-mean disturbance term. If ε_c is assumed to follow a normal distribution, the predicted value of dependent variable is unbounded, thus violating the [0, 1] constraint. This section discusses the stochastic implications of this constraint. As in Working's model, the share is unbounded and as the income elasticities of the logistic model are unappealing, we shall consider the implication in context of the MVE model.

As the standard deviation of the residuals is 0.075, the predicted food share in country c follows a normal distribution $N(\mu,\sigma^2)$ with $\mu = f(M_c)$, $\sigma = 0.075$, $c = 1,...,138$. The probability of the predicted share w_c being negative or greater than 1 is:

$$\begin{cases} P(w_c < 0) = P(\varepsilon < -f(M_c)) = \int_{-\infty}^{-f(M_c)} \varphi d\varepsilon, \\ P(w_c > 1) = P(\varepsilon > 1 - f(M_c)) = \int_{1-f(M_c)}^{+\infty} \varphi d\varepsilon, \end{cases} \quad c = 1,\ldots,138, \tag{3.2}$$

where φ is the density function of $N(\mu,\sigma^2)$ with $\mu = 0$, $\sigma = 0.075$. For example, the fitted food share in the US is 0.08 using the MVE model with $\hat{\alpha} = 1.1$, $\hat{\beta} = 0.6$ (from row 4 of Table 2.3). Integrating φ from $-\infty$ to -0.08, we have $P(w_{US} < 0) = 14\%$, and $P(w_{US} > 1) = 0$, which means there is 14% chance of the predicted food budget share in the US being negative. This is a non-trivial problem.

Figure 3.1 plots the residuals from the MVE model. The 138 countries are split into two groups, the "poor" and the "rich", with 69 countries in each.[9] The notes to this figure reveal that the standard deviation for the poor group is about twice of that for the rich group. Allowing for this heteroscedasticity by using $\sigma = 0.098$ for the poor and $\sigma = 0.042$ for the rich, Figure 3.2 shows the probability of the share being negative (dotted line) or greater than 1 (solid line). As can be seen, the very rich counties are more likely to be problematic, but less so than above when the heteroscedasticity was ignored. Now, there is still about 2% of the predicted food share in the US being negative. That is, the MVE model fails to solve the [0, 1] problem when the error term is normally distributed. On the other hand, there is no need to worry about $w > 1$ as the probability of this occurring is near zero in all countries.

To avoid the above problem, we use a logit transformation:

$$\log\left(\frac{w}{1-w}\right) = \log\left(\frac{\beta}{M + \alpha - \beta}\right) + \varepsilon', \tag{3.3}$$

with β and α as defined below equation (2.4). Now the range of left-hand side variable is $(-\infty,+\infty)$, and model (3.3) can be estimated by non-linear LS. Row 6 of Table 2.3 contains the results. Compared to

[9] Countries with income lower than 15 (with US=100) are called "poor" countries and the rest are "rich" countries.

the previous results in row 4, after the logit transformation the standard errors of both α and β decrease by more than 30%. Importantly, after the logit transformation the residuals are much closer to being normally distributed. As can be seen from row 4 and row 5, the p-value of the Lilliefors test statistic is 0.3% and 0.4%, which indicates that the normality hypothesis has to be rejected. After the logit transformation as shown in rows 6 and 7, however, the p-value increases to 3% (where observations are unweighted), and 4% (weighted to allow for heterscedasticity). Accordingly, not only does the logit deal with the [0, 1] constraint, it also facilitates reliable inference.

4. **Allowing for Price Differences**

The previous two sections ignored the cross-country differences in the relative price of food. In this section, we simultaneously take account of the differences in income and prices internationally by employing the differential approach to consumption theory (Theil 1980), which has the convenient property of dealing with the two determinants as separate additive terms.

Income and Price Variation across Countries

Let p_c be the food price in country c, p_{ic} be the price of commodity i $(i = 1, \ldots, n,$ including food) and $\log P_c = \sum_{i=1}^{n} w_{ic} \log p_{ic}$ be the Divisia price index in county c, with w_{ic} the budget share of commodity i in country c. The relative price of food in country c, $\log p_c - \log P_c$, is then comparable across countries. Figure 4.1 plots income and the relative food price in the 138 countries. Two things can be clearly seen from this figure. First, the dispersion of income is much larger than that of the relative food price -- almost 10 times larger on the basis of the standard deviation. The poorest country's (D. R. Congo) income is only 1/240 of that of the richest country, US, while the corresponding ratio of the relative food price is only 1.4, and the ratio of food share is only about 10. Second, food is relatively cheaper in rich countries (the correlation between income and the price of food is -0.47). Due to the substantially larger variability of income, it is unlikely that this correlation greatly influences the broad findings of the previous section that dealt with the effects of income alone. But as will be seen in Section 5, allowing for prices does have an important impact on the behaviour of the model at extreme values of income.

World Prices

The Engel functions (3.1) discussed above can be thought of as holding prices constant. In what follows, it is convenient to suppose that the price of food is held constant at the geometric mean of prices in the 138 countries, $\bar{p}$, which can be thought of as the "world" price. Let $\tilde{w}_c$ be the food budget share for country c when the price of food is $\bar{p}$, and it can be written as

$$\tilde{w}_c = f\left(M_c\right). \tag{4.1}$$

The observed food budget share, w_c, can then be expressed as the sum of $\tilde{w}_c$ and a term to account for the difference between the domestic and the world price,

$$w_c = f(M_c) + (w_c - \tilde{w}_c). \quad (4.2)$$

Income and Prices Combined

As discussed in Appendix A2, the term $w_c - \tilde{w}_c$ is the sum of two components: a pure price component and a substitution component,

$$w_c - \tilde{w}_c = \tilde{w}_c \left[\log \frac{p_c}{P_c} - \log \frac{\overline{p}}{\overline{P}} \right] + \phi\theta_c \left[\log \frac{p_c}{P'_c} - \log \frac{\overline{p}}{\overline{P}'} \right]. \quad (4.3)$$

The terms $\tilde{w}_c$ and θ_c on the right are budget and marginal shares at income M_c and price $\overline{p}$. The other terms in equation (4.3) are as follows. First, $\log p_c/P_c$ is the price of food in country c deflated by the Divisia index of all prices in c. Second, $\log \overline{p}/\overline{P}$ is the world price of food relative to the Divisia index of the world prices of all goods, with this index defined as $\sum_{i=1}^{n} \tilde{w}_i \log \overline{p}_i$, where $\tilde{w}_i = (1/138)\sum_{c=1}^{138} \tilde{w}_{ic}$ and $\log \overline{p}_i = (1/138)\sum_{c=1}^{138} \log p_{ic}$ are means over the 138 countries. As the two terms are combined in the first square brackets on the right-hand side of equation (4.3), this term involves a comparison of the relative price of food in country c with the corresponding world relative price. Third, the relative prices in the second set of square brackets are similar to those in the first, but now the two deflators are Frisch indexes, rather than Divisia. That is to say, the prices in these indexes are weighted by marginal shares, rather than budget shares: $\log P'_c = \sum_{i=1}^{n} \theta_{ic} \log p_{ic}$ and $\log \overline{P}' = \sum_{i=1}^{n} \theta_i \log \overline{p}_i$, where θ_{ic} is the marginal share of commodity i in country c and θ_i is the average across countries. Finally, $\phi < 0$ is the income flexibility (the reciprocal of the income elasticity of the marginal utility of income), which for reasons of simplicity, is taken to be a constant. It is to be noted that equation (4.3) holds under the simplifying assumption of preference independence, whereby the consumer's utility function is additive in two sub-utility functions, one for food and the other for the non-food group (all other goods), each of which depends only on the consumption of the commodity group in question. Such an assumption is probably not unreasonable given the broadness of the goods in question, food and non-food.

Combining equations (4.2) and (4.3), the observed food budget share in country c can be expressed as

$$w_c = f(M_c) + \tilde{w}_c \left[\log \frac{p_c}{P_c} - \log \frac{\overline{p}}{\overline{P}} \right] + \phi\theta_c \left[\log \frac{p_c}{P'_c} - \log \frac{\overline{p}}{\overline{P}'} \right] + \varepsilon_c. \quad (4.4)$$

There are four terms on the right-hand side of this equation. The first relates to the impact of country c's income on the food share, holding prices constant. The second term recognises that a higher food price raises food expenditure when the consumer buys the same quantity despite its higher price; this leads to an increase in the food budget share. The third term deals with the substitution effect whereby the consumer buys less food following a price increase, and more non-food goods. Finally, the disturbance term ε_c deals with all other factors influencing food consumption.

5. **The Income and Price Sensitivity of Consumption**

In this section, we apply model (4.4) to the ICP (2008) data and examine the implications. Since the two marginal shares add to 1, as do the two budget shares, this equation can be simplified to

$$w_c = \tilde{w}_c + \tilde{w}_c(1-\tilde{w}_c)x_c + \phi\theta_c(1-\theta_c)x_c + \varepsilon_c, \tag{5.1}$$

where $\tilde{w}_c = f(M_c)$, $x_c = \log(p_c/p_{nf,c}) - \log(\overline{p}/\overline{p}_{nf})$, $p_{nf,c}$ is the price of non-food in country c and $\overline{p}_{nf}$ is the geometric mean of non-food prices across countries. See Appendix A2 for details. The budget and marginal shares on the right-hand side of equation (5.1) depends on the form of the Engel function $f(M_c)$. As discussed in Section 2, the estimated value of the Box-Cox parameter γ in the generalised Working's model is near zero. Thus, we only consider three types of Engel functions: Working's, the logistic and the MVE model. In addition, the logit transformation is applied to the MVE model with price effect added:

$$\log\left(\frac{w_c}{1-w_c}\right) = \log\left(\frac{\tilde{w}_c}{1-\tilde{w}_c}\right) + x_c + \phi\frac{\theta_c(1-\theta_c)}{\tilde{w}_c(1-\tilde{w}_c)}x_c + \varepsilon'_c, \tag{5.2}$$

where $\tilde{w}_c$ and x_c are defined below equation (5.1). The error terms ε_c in (5.1) and ε'_c in (5.2) are assumed to be normally distributed with zero means.

The log-likelihood functions are maximised by the Newton-Raphson method, and the estimators are given in Panel B of Table 2.3. Compared to the estimates in Panel A, the R-square values mostly increase. The estimates of the income flexibility ϕ are of the order of -0.5, which agrees with previous results (see, e.g., Selvanathan and Selvanathan 2003). Figure 5.1 shows the implied Engel curves with and without the price effect and as can be seen, the curves become flatter when prices are included in the models.[10]

Extreme values

As mentioned above, a defect of Working's model is that the budget share may fall below 0 or higher than 1. The upper part of Table 5.1 explores the seriousness of this issue by using the estimates of Working's model to present for the US (the richest country) the number of years of income growth until the budget share turns negative. Thus, the second entry of column 3 of this panel shows that if income in the US grows at 3% p.a., then in 48 years (from 2005) income hits the critical value at which the food share becomes negative.[11] While a defect of the model that occurs almost half a century into the future might be regarded as being of little practical significance, the same is not true for the income elasticity. From the second last entry of the lower part of Table 5.1, when income grows at the same rate (3%), the

[10] To establish the role of prices, suppose $\log p_c/P_c = \lambda + \gamma \log M_c$, with $\gamma < 0$. Write a simplified version of equation (4.4) under Working's model as $w_c = \alpha + \beta \log M_c + (\tilde{w}_c + \phi\theta_c)\log p_c/P_c + \varepsilon_c = \alpha' + [\beta + (\tilde{w}_c + \phi\theta_c)\gamma]\log M_c + \varepsilon_c$. As ϕ and θ_c are both fractions with $\tilde{w}_c > \theta_c$ (Engel's law), it follows that $\tilde{w}_c + \phi\theta_c > 0$. Furthermore, as $\gamma < 0$, the "coefficient" of income when prices are excluded is $|\beta + (\tilde{w}_c + \phi\theta_c)\gamma|$, which is greater than $|\beta|$, the corresponding coefficient when prices are included. This shows that the Engel curve without prices is steeper than when they are included.

[11] The corresponding 95% confidence interval is [29, 67] years. As shown in the notes to Table 5.1, this income growth of 3% is not too different to recent US experience. But as a sensitivity check, the results are redone with two other growth rates. As shown by the first and third entries of column 3 of Table 5.1. When income is taken to grow at 1% (5%) p.a., the share turns negative in 144 (29) years.

food income elasticity becomes negative in 15 years in the US. In other words, under Working's model food is projected to switch from a normal good to an inferior one in about 2020. While this cannot be completely ruled out, such a fundamental change in food consumption stretches economic credibility.[12]

As the Engel curve becomes flatter when the price effect is added, the above critical income values are even closer to the observed income when the prices are excluded in the model. This can be seen by comparing the results of column 2 of Table 5.1 (prices excluded) with those of column 3 (prices included). That is, the role of the relative price of food is to reduce the defect.

As discussed in Section 3, the budget share implied by the stochastic version of the MVE model is unbounded. The predicted food share in country c in t years may lie outside [0, 1]. When income grows at rate r, the probability of the share being negative in some future year t is given as:

$$P(w_c^t < 0) = \int_{-\infty}^{-\hat{w}_c^t} \varphi d\varepsilon, \qquad \text{where} \quad \hat{w}_c^t = \frac{\hat{\beta}}{M_c^t + \hat{\alpha}} \quad \text{and} \quad M_c^t = M_c^0 e^{rt}. \tag{5.3}$$

Here, M_c^t is the income of county c in t years, M_c^0 is its initial income, $\hat{w}_c^t$ is the fitted share and $\hat{\alpha}$ and $\hat{\beta}$ are estimates of parameters (estimated after making the appropriate modification to allow for price differences, from row 10 of Table 2.3). Panel A of Figure 5.2 shows the relations between these variables. The upper left quadrant gives the future projection of income and the Engel curve is in the upper right quadrant. Income grows to M^* in t^* years at point A and the food share declines to w^* at point B. The corresponding probability of the share being negative is given by equation (5.3). Let this probability be p^*, which is represented in the lower right quadrant of the figure by the point C. The relationship between years of future growth and the probability is given in the lower left quadrant. The probability rises and approaches one half as time passes. Panel B plots this positively-shaped probability relationship for the case of the US with three different growth rates. For example, when US income grows at 3% p. a., in 23 years' time there is a 20% chance of the food share being negative. If, alternatively, the annual rate is 1% (or 5%), the income will reach this point in 65 (or 13) years. This could be a nontrivial problem when there are large changes in income, such as in the analysis of long-term projections.

In Section 3, we found that when prices were excluded from the MVE model, the problem of a share exceeding unity was near zero for all countries. When prices are included, the same result holds. In particular, the estimates of both Working's and the MVE models with prices included imply that the critical values of income when $w = 1$ are so far below that of the poorest country that this defect of the two models can be safely ignored.

The findings on extreme values of income can be summarised as follow. At very high income level, Working's model fails "stress testing" as food becomes inferior and the expenditure on food becomes negative, which is logically impossible. The MVE model avoids these two defects but still fails stochastic

[12] In all of economic history, food has never been observed to be inferior. On the other hand however, the income projected for the US in 2019 has also never been observed before for any other country. Fogel (2004) argues that over the (very) longer term, due to "technophysio evolution" the size of the body of the human species adapts to economic circumstances, so that a fixed stomach size would not be a physical constraint on food consumption. Needless to say, it is appropriate to exercise some caution when interpreting these types of projections into the future.

stress testing. The food share implied in the MVE model can be negative with a nonzero probability. But we showed that a negative food share never occurs if the logit transform is applied to the MVE model.

Income and Price Elasticities

In this subsection, we analyse the income and price sensitivity of consumption by presenting the elasticities implied by the estimates. These elasticities are not constant but vary with different levels of affluence. The income elasticities from the three models are quite similar to those of Figure 2.2 since the price effect tends to be smaller compared to the income effect, which also can be seen from Figure 5.1. Table 5.2 summaries the income elasticities. As can be seen, the elasticities are fairly similar across models and, and there is a substantial gap between the maximum (which pertains to a poor country) and the minimum (a rich country) for all four cases.

We consider three types of own-price elsticities for food: Frisch (which holds the marginal utility of income constant), Slutsky (real income constant) and Cournot (money income constant). As discussed in Appendix A3, these can be expressed as

$$F = \phi\eta,\ S = F - \phi\theta\eta,\ C = F - (\phi\eta + 1)\theta, \tag{5.4}$$

where ϕ, η and θ are either from, or implied by, the estimates of rows 8-10 and 11 of Table 2.3. Expression (5.4) reveals that Frisch and Slutsky are linearly dependent on the income elasticity η, with slopes ϕ and $\phi(1-\theta)$, respectively. As $0 \le \theta,\ \eta \le 1,\ \phi \le 0$ and is likely to be greater than -1, it follows that $|S| \le |F| \le |C|$.

Figure 5.3 plots the price elasticities against income. The elasticities are larger in absolute values for low-income countries than for high-income ones. This pattern is in accordance with Timmer's (1981) proposition. The three types of elasticities converge when moving from poor to rich countries as the food marginal share decreases. But as the income elasticity in the logistic model is not monotonically decreasing (see Panel C of Figure 2.2), the implied price elasticities do not follow Timmer's proposition. For poor countries, the substantial role of the income effect in the price elasticity is clearly apparent in all three cases. For example, for both Working's and the MVE model, when income is about \$2,500, the Cournot elasticity (which includes the income effect) is about twice the value of Slutsky (income effect excluded).

6. **Conclusions**

This paper has dealt with economic aspects of the consumption of food, which occupies a dominant role in the budget for the majority of countries, especially poor ones. We examined the economic implications of several popular Engel curves, in particular the plausibility of the behaviour of the income elasticity of food and whether or not the models respect the [0, 1] domain of the budget share (the proportion of income devoted to the good).

A prominent model is Working's (1943), whereby the budget share is a linear function of the logarithm of income. This functional form, which underlies the almost ideal model of Deaton and Muellbauer (1980), tends to fit well but implies that the share becomes greater than one or negative at low and high values of income. This can be a major defect when analysing cross-country data that exhibit great disparities in incomes. Using the recently-published International Comparisons Program (2008) data for 138 countries that range from the very poorest to the richest, we investigated the seriousness of this problem. We found that this issue can present substantial difficulties, but the problem becomes less severe when the impact of cross-country differences in prices is properly controlled for. But even then, however, the defect does not completely disappear. In response, we proposed an alternative model that fits at least as well as Working's, but has the advantage that the budget share is always a positive fraction. A logit transform enhances the econometric performance of the model such that there is a zero probability of the share violating the [0, 1] range.

The demand model introduced in this paper refers to the food share (w) in a given country, and can be expressed as:

$$w = \frac{\beta}{M+\alpha} + \Pi_1 \left[\log \frac{p_f}{\overline{p}_f} - \log \frac{p_{nf}}{\overline{p}_{nf}} \right], \tag{5.5}$$

which is the sum of an income effect and a price effect. Here, M is income and $\log\left(p_f/\overline{p}_f\right)$ $\left(\log\left(p_{nf}/\overline{p}_{nf}\right)\right)$ is the logarithm of the food (non-food) price deflated by the world food (non-food) price, so that the whole term $\left[\log\left(p_f/\overline{p}_f\right) - \log\left(p_{nf}/\overline{p}_{nf}\right)\right]$ is the relative price of food. The coefficient of this price term is $\Pi_1 = \tilde{w}_f \tilde{w}_{nf} + \phi\theta_f\theta_{nf}$, where $\tilde{w}$ and θ are budget and marginal shares (of food and non-food, indicated by the subscripts f and nf, respectively) at world prices, and ϕ is the income flexibility (the reciprocal of the income elasticity of the marginal utility of income). The terms α and β are parameters. With the logit transform L: $L(x) = \log\left(x/(1-x)\right)$, the equation above becomes

$$L(w) = L\left(\frac{\beta}{M+\alpha}\right) + \Pi_2 \left[\log \frac{p_f}{\overline{p}_f} - \log \frac{p_{nf}}{\overline{p}_{nf}} \right], \tag{5.6}$$

where the coefficient of price effect is now $\Pi_2 = \Pi_1 / \tilde{w}_f \tilde{w}_{nf}$. This model is attractive in its simplicity and seems to perform well empirically. It also possesses advantages over alternative models, advantages that were mentioned in the previous paragraph.

Using the recently-published data on consumption in 138 countries by the International Comparison Program (2008), our estimates imply the following income and price elasticities for food consumption:

Country characteristics			Food demand elasticities		
Level of affluence	Income per capita ($US of 2005)	Food budget share (%)	Income elasticity	Price elasticity	
				Cournot	Slutsky
Very poor	1,010	46	0.90	-0.70	-0.33
Poor	3,335	35	0.74	-0.57	-0.32
Rich	8,750	21	0.53	-0.39	-0.27
Very rich	20,979	11	0.31	-0.22	-0.17
Average	8483	28	0.62	-0.47	-0.27

As can be seen, the food share declines dramatically as income rises, from 46% for the very poor to 11% for the very rich (Engel's law). Moreover, the food income elasticity falls quite rapidly from 0.9 to 0.3, as does the (absolute value of the) Cournot price elasticity (which holds money income constant), reflecting the role of the income effect of food price changes. The Slutsky price elasticity (real income constant) also falls with income, but not as fast. If we were to pick a country at random, the best guess of the food income elasticity is 0.6, the average value. But if we know it is very rich (poor), the elasticity to use is 0.3 (0.9).

Appendices

A1. <u>The Data</u>

The data are from ICP (2008), which provides data on individual expenditures and prices of 12 broad categories of goods in 146 countries in 2005. As in eight of these countries expenditure on at least one item is recorded as zero, we exclude these countries, so 138 countries remain. The eight excluded countries are Burundi, Comoros, Ethiopia, Gambia, Tanzania, Uganda, Zambia and Zimbabwe.

Table 5 of ICP (2008) gives nominal expenditures on the 12 commodities in each of the 138 countries. The budget share of food is calculated from this table as the proportion of total expenditure on the 12 commodities devoted to this good. These food shares are given in Table 2.1 in the text. For income, we use per capita total real expenditure on the 12 goods, which is provided in Table 6 of ICP (2008). The prices used are obtained from Table 1 of ICP (2008).

A2. <u>Derivations</u>

This Appendix uses the differential approach (Theil 1980, Theil et al. 1989) to derive several results of the text.

The Differential Approach

We consider that the consumer's budget is made up of two goods, food and non-food (the 11 goods aggregated into non-food). Let p_f be the price of food and p_{nf} be the price of non-food, and q_f and q_{nf} be the corresponding quantities consumed. Income is then $M = p_f q_f + p_{nf} q_{nf}$ and $w_f = p_f q_f / M$ is the budget share of food. The differential of w_i is $dw_i = w_i d(\log p_i) + w_i d(\log q_i) - w_i d(\log M)$, for $i = f,$ nf. Define the Divisia price index as $d(\log P) = \sum_i w_i d(\log p_i)$. Adding and subtracting this index from the right of the above equation, we have
$dw_i = w_i\left[d(\log p_i) - d(\log P)\right] + w_i d\log(q_i) - w_i d(\log Q)$, where
$d(\log Q) = d(\log M) - d(\log P)$ is the change in real income. When real income is fixed,
$d(\log Q) = 0$, so that

$$dw_i = w_i\left[d(\log p_i) - d(\log P)\right] + w_i d(\log q_i), \tag{A2.1}$$

which shows that the change in the budget share is the sum of a direct relative price term and a quantity component.

The quantity component of the change in the share deals with the substitution effects of price changes. To analyse this, consider a Marshallian demand equation for good i, $q_i = q_i(M, p_f, p_{nf})$, so that $dq_i = (\partial q_i / \partial M) dM + \sum_{j \in \{f,nf\}} (\partial q_i / \partial p_j) dp_j$. Multiplying both sides by p_i / M and using $dx/x = d(\log x)$, we have

$$w_i d(\log q_i) = \frac{\partial(p_i q_i)}{\partial M} d(\log M) + \sum_{j \in \{f,nf\}} \frac{p_i p_j}{M} \frac{\partial q_i}{\partial p_j} d(\log p_j).$$

Using Barten's (1964) fundamental matrix equation, and defining $\theta_i = \partial(p_i q_i)/\partial M$ as the marginal share for good i, $\nu_{ij} = (\lambda/M) p_i p_j u^{ij}$ as the price coefficient for good i and j, with λ the marginal utility of income and u^{ij} the $(i, j)^{th}$ element of the inverse of the Hessian matrix of the utility function, and $\phi = (\partial \log \lambda / \partial \log M)^{-1} < 0$ as the income flexibility, the above equation can be expressed as

$$w_i d(\log q_i) = \theta_i d(\log Q) + \sum_{j \in \{f,nf\}} (\nu_{ij} - \phi \theta_i \theta_j) d(\log p_j).$$

As the price coefficients satisfy

$$\sum_{j \in \{f,nf\}} \nu_{ij} = \phi \theta_i, \qquad i = f,\ nf, \tag{A2.2}$$

the demand equation can be further simplified to

$$w_i d(\log q_i) = \theta_i d(\log Q) + \sum_{j \in \{f,nf\}} \nu_{ij} \left[d(\log p_j) - d(\log P') \right], \tag{A2.3}$$

where $d(\log P') = \sum_{k \in \{f,nf\}} \theta_k d(\log p_k)$ is the Frisch price index that uses marginal shares as weights. Formulation (A2.3) makes clear the interpretation of the ν_{ij} as price coefficients. Under preference independence, the utility function is additive (up to some monotonic transformation) and its Hessian and inverse are both diagonal matrices. This means that $\nu_{ij} = 0$ for $i \neq j$ and in view of constraint (A2.2), $\nu_{ii} = \phi \theta_i$, $i = f, nf$. In this case, equation (A2.3) then contains only the own price:

$$w_i d(\log q_i) = \theta_i d(\log Q) + \phi \theta_i \left[d(\log p_i) - d(\log P') \right].$$

When real income is constant, the first term on the right of the above vanishes and equation (A2.1) becomes

$$dw_i = w_i \left[d(\log p_i) - d(\log P) \right] + \phi \theta_i \left[d(\log p_i) - d(\log P') \right]. \tag{A2.4}$$

Equation (4.3)

Let $\overline{p}_f$ and $\overline{p}_{nf}$ be the geometric means over countries of the food and non-food prices; these can be thought of as "world" prices. Furthermore, let $\tilde{w}_{ic}$ be the budget share of good i in country c evaluated at c's real income, Q_c, and these world prices. We then interpret dw_i as $w_{ic} - \tilde{w}_{ic}$, the difference between the observed budget share and that corresponding to world prices; $d(\log p_i)$ as $\log p_{ic} - \log \overline{p}_i$, the difference between the observed and the world price; $d(\log P)$ as $\log P_c - \log \overline{P}$; and $d(\log P')$ as

$\log P_c' - \log \overline{P}'$. From the mean value theorem of differential calculus and treating ϕ as a constant, equation (A2.4) then becomes

$$w_{ic} - \tilde{w}_{ic} = w_i^* \left[\log \frac{p_{ic}}{\overline{p}_i} - \log \frac{P_c}{\overline{P}} \right] + \phi \theta_{ic}^* \left[\log \frac{p_{ic}}{\overline{p}_i} - \log \frac{P_c'}{\overline{P}'} \right], \qquad \text{(A2.5)}$$

where w_{ic}^* and θ_{ic}^* are the budget and marginal shares of good i at country c's observed income and prices that lie between $\mathbf{p}_c = \left[p_{fc}, p_{nf,c} \right]$ and $\overline{\mathbf{p}} = \left[\overline{p}_f, \overline{p}_{nf} \right]$. As an approximation, we evaluate these shares at Q_c and $\overline{\mathbf{p}} = \left[\overline{p}_f, \overline{p}_{nf} \right]$, so that w_{ic}^* (θ_{ic}^*) becomes $\tilde{w}_{ic}$ (θ_{ic}). After minor rearrangements and omitting the subscript $i = f$ for food, equation (A2.5) becomes

$$w_c - \tilde{w}_c = \tilde{w}_c \left[\log \frac{p_c}{P_c} - \log \frac{\overline{p}}{\overline{\overline{P}}} \right] + \phi \theta_c \left[\log \frac{p_c}{P_c'} - \log \frac{\overline{p}}{\overline{\overline{P}}'} \right], \qquad \text{(A2.6)}$$

which is equation (4.3) in the text.

Applying the logit transformation to equation (A2.4), dw_i is replaced by $w_i (1 - w_i) d \log (w_i / 1 - w_i)$, and we have

$$d \log \left(\frac{w_i}{1 - w_i} \right) = \frac{1}{w_i (1 - w_i)} \left(w_i \left[d(\log p_i) - d(\log P) \right] + \phi \theta_i \left[d(\log p_i) - d(\log P') \right] \right). \qquad \text{(A2.7)}$$

Following the same steps used to obtain equation (A2.6) from equation (A2.4), equation (A2.7) becomes:

$$L(w_c) - L(\tilde{w}_c) = \frac{\tilde{w}_c}{\tilde{w}_c (1 - \tilde{w}_c)} \left[\log \frac{p_c}{P_c} - \log \frac{\overline{p}}{\overline{\overline{P}}} \right] + \frac{\phi \theta_c}{\tilde{w}_c (1 - \tilde{w}_c)} \left[\log \frac{p_c}{P_c'} - \log \frac{\overline{p}}{\overline{\overline{P}}'} \right], \qquad \text{(A2.8)}$$

with the function $L(a) = \log \left[a/(1-a) \right]$, for $0 < a < 1$.

Equations (5.1), (5.2) and (3.3)

As p_c is the price of food in country c and $p_{nf,c}$ is the non-food price, $\log \left(p_c / p_{nf,c} \right)$ is the relative price of food and $x_c = \log(p_c / p_{nf,c}) - \log(\overline{p}_c / \overline{p}_{nf,c})$ is this relative price as compared to the corresponding world relative price. In view of the budget constraint, $\tilde{w}_{nf,c} = 1 - \tilde{w}_c$, and $\theta_{nf,c} = 1 - \theta_c$, so that equation (A2.6) for food simplifies to

$$w_c = \tilde{w}_c + \tilde{w}_c (1 - \tilde{w}_c) x_c + \phi \theta_c (1 - \theta_c) x_c, \qquad \text{(A2.9)}$$

where $\tilde{w}_c = f(M_c)$. Similarly, and after the logit transform, equation (A2.8) simplifies to

$$L(w_c) = L(\tilde{w}_c) + x_c + \phi \frac{\theta_c (1 - \theta_c)}{\tilde{w}_c (1 - \tilde{w}_c)} x_c. \qquad \text{(A2.10)}$$

When the disturbance term is included, equation (A2.9) is equation (5.1) and (A2.10) is (5.2) in Section 5 of the text. When prices are constant, $x_c = 0$ and $\tilde{w}_c = \beta / (M + \alpha)$ under the MVE model. Applying equation (A2.10) to this case, we have $L(w_c) = \log \left(\beta / (M_c + \alpha - \beta) \right)$, which is equation (3.3) in text once the disturbance is allowed for.

A3. <u>The Price Elasticities</u>

It can be shown that equation (A2.3) can be expressed as $w_i d(\log q_i) = \theta_i \phi d(\log \lambda) + \sum_{j\in\{f,nf\}} \nu_{ij} d(\log p_j)$, where λ is the marginal utility of income. This shows that ν_{ij} measures the response of consumption of good i to a change in the price of j, the other prices remaining constant and when income is compensated to keep the marginal utility of income constant. Thus, when we divide both sides of the above equation by w_i, $F_{ij} = \nu_{ij}/w_i$ emerges as the $(i, j)^{th}$ Frisch price elasticity.

The Slutsky price elasticity measures the price sensitivity of consumption when real income remains unchanged. This is also referred to as the "pure substitution effect". To derive this elasticity, use constraint (A2.2) to write equation (A2.3) in absolute price form

$$w_i d(\log q_i) = \theta_i d(\log Q) + \sum_{j\in\{f,nf\}} \pi_{ij} d(\log p_j),$$

where $\pi_{ij} = \nu_{ij} - \phi\theta_i\theta_j$ is the $(i, j)^{th}$ Slutsky coefficient. This shows that the $(i, j)^{th}$ Slutsky price elasticity is $S_{ij} = F_{ij} - \phi\theta_i\theta_j/w_i$. The Cournot price elasticity refers to the situation when price of j changes while nominal income remains constant, so that real income changes. As $d(\log Q) = d(\log M) - d(\log P)$, where $d(\log P) = \sum_{j\in\{f,nf\}} w_j d(\log p_j)$, equation (A2.3) can be expressed as $w_i d(\log q_i) = \theta_i d(\log M) + \sum_{j\in\{f,nf\}} (\pi_{ij} - \theta_i w_j) d(\log p_j)$. The Cournot price elasticity is thus $C_{ij} = S_{ij} - \theta_i w_j/w_i$. This measure includes both the pure substitution effect and the income effect of the price change.

Under preference independence, the $(i, j)^{th}$ price coefficient $\nu_{ij} = \phi\theta_i\delta_{ij}$, where δ_{ij} is the Kronecker delta ($\delta_{ij} = 1$ if $i = j$ and 0 otherwise). If we write $\eta_i = \theta_i/w_i$ for the income elasticity of i, under preference independence the three types of price elasticity then can be expressed as $F_{ij} = \delta_{ij}\phi\eta_i$, $S_{ij} = F_{ij} - \phi\theta_j\eta_i$ and $C_{ij} = S_{ij} - \eta_i w_j$, which coincide with equation (5.4) for $i = j = \text{food}$.

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TABLE 2.1

REAL INCOME AND FOOD BUDGET SHARE IN 138 COUNTRIES, 2005

Country	Income per capita	Food share	Country	Income per capita	Food share	Country	Income per capita	Food share
1. United States	100.0	6.2	47. Belarus	27.3	34.7	93. Kyrgyz	8.0	40.8
2. Luxembourg	92.2	6.9	48. Kazakhstan	26.5	18.6	94. Sri Lanka	7.9	36.4
3. Iceland	80.7	8.9	49. Mauritius	26.3	23.4	95. Iraq	7.8	32.1
4. Norway	77.7	9.7	50. Russia	26.3	25.5	96. Mongolia	7.7	35.9
5. United Kingdom	76.9	7.1	51. Bulgaria	26.1	19.5	97. Tajikistan	7.7	55.0
6. Austria	76.4	8.7	52. Iran	25.2	23.4	98. Philippines	7.5	43.9
7. Switzerland	74.6	9.3	53. Romania	24.4	25.0	99. Indonesia	7.4	41.6
8. Canada	74.4	7.7	54. Oman	24.2	22.1	100. Pakistan	7.3	48.8
9. Netherlands	72.4	8.2	55. Argentina	24.0	22.5	101. Morocco	7.2	31.1
10. Sweden	72.0	8.3	56. Serbia	23.7	25.6	102. Lesotho	7.1	35.5
11. France	71.5	10.6	57. Saudi Arabia	23.6	18.5	103. China	7.0	24.1
12. Australia	70.6	8.5	58. Chile	23.3	16.2	104. Vietnam	6.8	31.3
13. Denmark	69.8	8.1	59. Uruguay	22.1	19.0	105. India	5.5	33.7
14. Belgium	68.4	10.3	60. Bosnia Herz.	21.9	28.5	106. Cambodia	5.3	47.2
15. Germany	67.5	9.1	61. Macedonia	20.5	30.9	107. Yemen	5.2	41.1
16. Hong Kong	66.3	8.9	62. Ukraine	19.8	32.1	108. Sudan	4.5	55.6
17. Ireland	66.2	4.6	63. South Africa	19.3	17.6	109. Lao P.D.R.	4.4	47.3
18. Japan	66.0	12.3	64. Malaysia	19.3	17.3	110. Djibouti	4.4	33.6
19. Taiwan	64.5	14.8	65. Turkey	18.9	23.1	111. Kenya	4.3	33.3
20. Cyprus	63.4	13.7	66. Montenegro	18.7	32.2	112. Sao Tome P.	4.3	53.7
21. Finland	63.0	9.3	67. Brazil	18.7	15.5	113. Congo, R.	4.1	37.5
22. Spain	61.9	11.8	68. Venezuela	17.1	26.1	114. Cameroon	4.0	43.4
23. Italy	61.6	12.3	69. Thailand	16.1	15.9	115. Nigeria	4.0	56.7
24. Greece	59.4	13.8	70. Albania	14.6	24.6	116. Senegal	3.9	48.9
25. NZ	57.7	11.5	71. Colombia	14.5	24.3	117. Chad	3.5	55.0
26. Israel	54.7	12.9	72. Ecuador	13.7	25.9	118. Mauritania	3.4	63.6
27. Malta	54.3	13.9	73. Jordan	13.7	28.9	119. Nepal	3.4	48.7
28. Singapore	53.6	8.2	74. Tunisia	13.7	24.8	120. Bangladesh	3.3	49.9
29. Qatar	50.5	13.6	75. Peru	13.6	29.2	121. Benin	3.3	43.6
30. Slovenia	50.0	11.9	76. Egypt	13.5	41.6	122. Ghana	3.3	49.2
31. Portugal	49.0	13.1	77. Armenia	13.1	65.1	123. Coted 'Ivoire	3.1	43.3
32. Brunei	48.7	18.4	78. Moldova	13.0	24.2	124. S. Leone	3.1	42.4
33. Kuwait	47.0	14.8	79. Maldives	12.9	22.9	125. M'gascar	3.0	57.0
34. Czech	46.3	13.1	80. Gabon	12.7	36.3	126. Togo	2.7	48.6
35. Hungary	42.6	13.3	81. Fiji	12.6	26.3	127. Burkina Faso	2.5	42.0
36. Bahrain	41.6	19.0	82. Georgia	12.1	36.7	128. Guinea	2.4	44.0
37. Korea	40.4	13.7	83. Botswana	11.9	21.9	129. Mali	2.3	46.7
38. Estonia	39.4	15.4	84. Namibia	10.9	26.0	130. Angola	2.3	40.7
39. Slovak	38.8	15.7	85. Swaziland	10.8	41.9	131. Malawi	2.1	23.3
40. Lithuania	38.3	22.9	86. Azerbaijan	10.5	57.9	132. Rwanda	2.1	42.7
41. Poland	36.7	17.8	87. Syrian Arab	10.5	41.7	133. C. Africa	1.9	56.8
42. Croatia	36.1	19.3	88. Bolivia	10.2	27.8	134. M'bique	1.7	60.1
43. Macao	36.1	13.3	89. Equat. Guinea	10.1	39.5	135. Liberia	1.3	25.8
44. Latvia	33.4	19.2	90. Paraguay	9.9	32.3	136. Niger	1.3	46.4
45. Lebanon	32.0	27.8	91. Cape Verde	8.8	28.8	137. G-Bissau	1.2	52.3
46. Mexico	28.7	22.0	92. Bhutan	8.0	34.5	138. Congo, D. R.	0.4	62.2

Notes: 1. Income is real total consumption expenditure per capita in international dollars with US=100.
2. Food shares are in percentage form.
3. The grey line splits the 138 countries into two groups, the "rich" and the "poor".

Source: ICP (2008). For details, see Appendix A1.

TABLE 2.2

SUMMARY OF FORMS OF ENGEL CURVES FOR FOOD

Model	Budget share	Marginal share	Income elasticity	Extreme values of income when			Strengths	Weaknesses
				$w=0$	$w=1$	$\eta=0$		
Working's	$w=\alpha+\beta\log M$	$\theta=w+\beta$	$\eta=1+\beta/w$	$M_0^*=e^{-\frac{\alpha}{\beta}}$	$M_1^*=e^{\frac{1-\alpha}{\beta}}$	$M^{**}=e^{-\frac{\alpha+\beta}{\beta}}$	1. Fits well 2. η declines as income rises	1. w may lie outside [0,1] interval 2. η can be <0
Generalised Working's	$w=\alpha M^{\gamma}+\beta M^{(\gamma)}$	$\theta=(\gamma+1)w+\beta$	$\eta=\gamma+1+\beta/w$	$M_0^*=\left(\frac{\beta}{\alpha\gamma+\beta}\right)^{\frac{1}{\gamma}}$	$M_1^*=\left(\frac{\beta+\gamma}{\alpha\gamma+\beta}\right)^{\frac{1}{\gamma}}$	$M^{**}=\left(\frac{\beta/(\gamma+1)}{(\alpha\gamma+\beta)}\right)^{\frac{1}{\gamma}}$	1. As above 2. Approaches Working's model when $\gamma\to 1$	As above
Logistic	$w=\frac{\alpha+\beta e^{M}}{1+e^{M}}$	$\theta=k(\beta-\alpha)+w$ $k=Me^{M}/(1+e^{M})^2>0$	$\eta=1+k\frac{\beta-\alpha}{w}$	-	-	-	1. w lies in [0,1] 2. η is always positive	$\eta\to 1$ for poorest and richest consumers
MVE	$w=\frac{\beta}{M+\alpha}$	$\theta=\frac{\alpha}{M+\alpha}w$	$\eta=\frac{\alpha}{M+\alpha}$	$M_0^*=\infty$	$M_1^*=\beta-\alpha$	-	1. η declines as income rises 2. w and η always positive	

TABLE 2.3

ESTIMATES OF DEMAND MODELS FOR FOOD

Model	Parameters				R^2	p-values of Lilliefors test
	α	β	γ	ϕ		
(1)	(2)	(3)	(4)	(5)	(6)	(7)
			A. Income effect only			
1. Working's	0.278 (0.007)	-0.112 (0.006)			0.7487	0
2. Generalised Working's	0.278 (0.013)	-0.111 (0.009)	-0.0008 (0.0001)		0.7488	0
3. Logistic	0.889 (0.029)	0.090 (0.011)			0.7614	0.0031
4. MVE - unweighted	1.106 (0.121)	0.602 (0.048)			0.7669	0.0028
5. MVE - weighted	1.063 (0.095)	0.581 (0.031)			0.7917	0.0036
6. MVE - logit/unweighted	1.000 (0.066)	0.554 (0.031)			0.7730	0.0339
7. MVE - logit/weighted	0.984 (0.066)	0.547 (0.026)			0.7805	0.0378
			B. Income and price effect			
8. Working's	0.277 (0.007)	-0.084 (0.007)		-0.588 (0.135)	0.7970	0.0067
9. Logistic	0.731 (0.044)	0.133 (0.013)		-0.516 (0.131)	0.7971	0.0191
10. MVE - unweighted	1.791 (0.274)	0.818 (0.090)		-0.585 (0.137)	0.8009	0.0017
11. MVE - weighted	1.595 (0.190)	0.747 (0.068)		-0.594 (0.084)	0.8874	0.0094
12. MVE - logit/unweighted	1.877 (0.226)	0.837 (0.064)		-0.579 (0.139)	0.7811	> 0.1
13. MVE - logit/weighted	1.938 (0.233)	0.851 (0.061)		-0.578 (0.148)	0.7863	>0.1

Notes: 1. Standard errors or asymptotic standard errors are in parentheses.

2. R^2 values are defined as $\sum_{c=1}^{138}\left(\hat{w}_c - \bar{\hat{w}}\right)^2 \Big/ \sum_{c=1}^{138}\left(w_c - \bar{w}\right)$, where $\hat{w}_c$ is the fitted food share in country c and a bar denotes the mean.

3. "Logit" means that the logit transformation is applied for estimation. "Weighted" means that different variances for the poor and rich countries are allowed for in estimation.

4. Observed incomes are divided by 5,000.

5. The Lilliefors test for normality is an adaptation of the Kolmogorov–Smirnov test.

TABLE 5.1

EXTREME VALUES OF INCOME IN US

(Number of years growth in income until food share and income elasticity hit zero)

Problem	Price effects	
	Excluded	Included
(1)	(2)	(3)
$w = 0$, when income grows at		
1% p.a.	62.6 [33.8, 91.4]	144.2 [87.8, 200.4]
3% p.a.	20.9 [11.3, 30.5]	48.1 [29.3, 66.8]
5% p.a.	12.6 [6.8, 18.3]	28.8 [17.6, 40.1]
$\eta = 0$, when income grows at		
1% p.a.	--	44.2 [-12.1, 100.4]
3% p.a.	--	14.7 [-4.0, 33.5]
5% p.a.	--	8.8 [-2.4, 20.1]

Notes: 1. The annual percentage growth rates of real personal consumption expenditure per capita in the US in each year between 2003 to 2008 are 2.8, 3.5, 3.4, 2.9, 2.6, and -0.2 (US Bureau of Economic Analysis), with an average of 2.5%.

2. 95% confidence intervals are in square brackets.

TABLE 5.2

INCOME ELASTICITIES OF DEMAND FOR FOOD AND NON-FOOD

	Working's model		Logistic model		MVE model		Logit MVE model	
	Food	Non-food	Food	Non-food	Food	Non-food	Food	Non-food
Mean	0.65	1.12	0.71	1.10	0.61	1.12	0.62	1.11
Max	0.86	1.20	0.99	1.18	0.99	1.15	0.99	1.15
Min	0.36	1.10	0.39	1.01	0.22	1.01	0.23	1.01
SD	0.13	0.02	0.19	0.05	0.23	0.03	0.23	0.03

Notes: 1. The income elasticity of food in country c is $\eta_c = \theta_c / w_c$. Expressions for the marginal and budget shares of food (θ_c and w_c, respectively) are given in Table 2.1. As a budget-share weighted average of the income elasticities of food and its complement non-food is unity, the non-food elasticity is $(1 - w_c\eta_c)/(1 - w_c)$.

2. Price effects are included in each model (Panel B of Table 2.3).

FIGURE 2.1

SCATTER OF FOOD BUDGET SHARE AGAINST INCOME

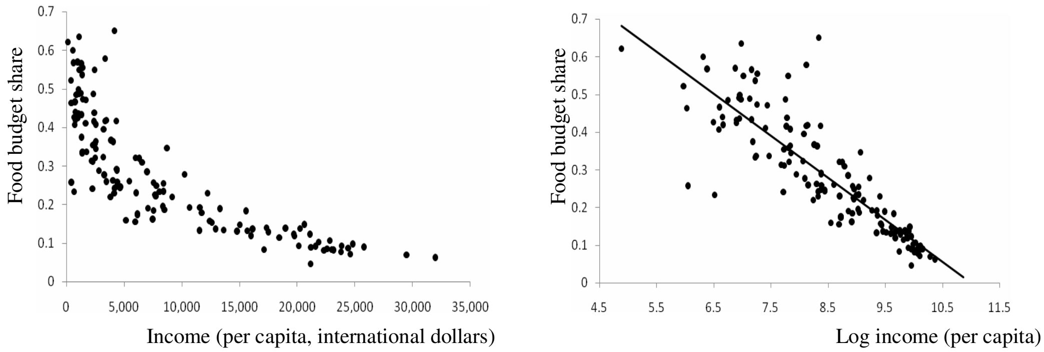


FIGURE 2.2

ESTIMATED INCOME ELASTICITIES, MARGINAL SHARES
AND BUDGET SHARES OF FOOD

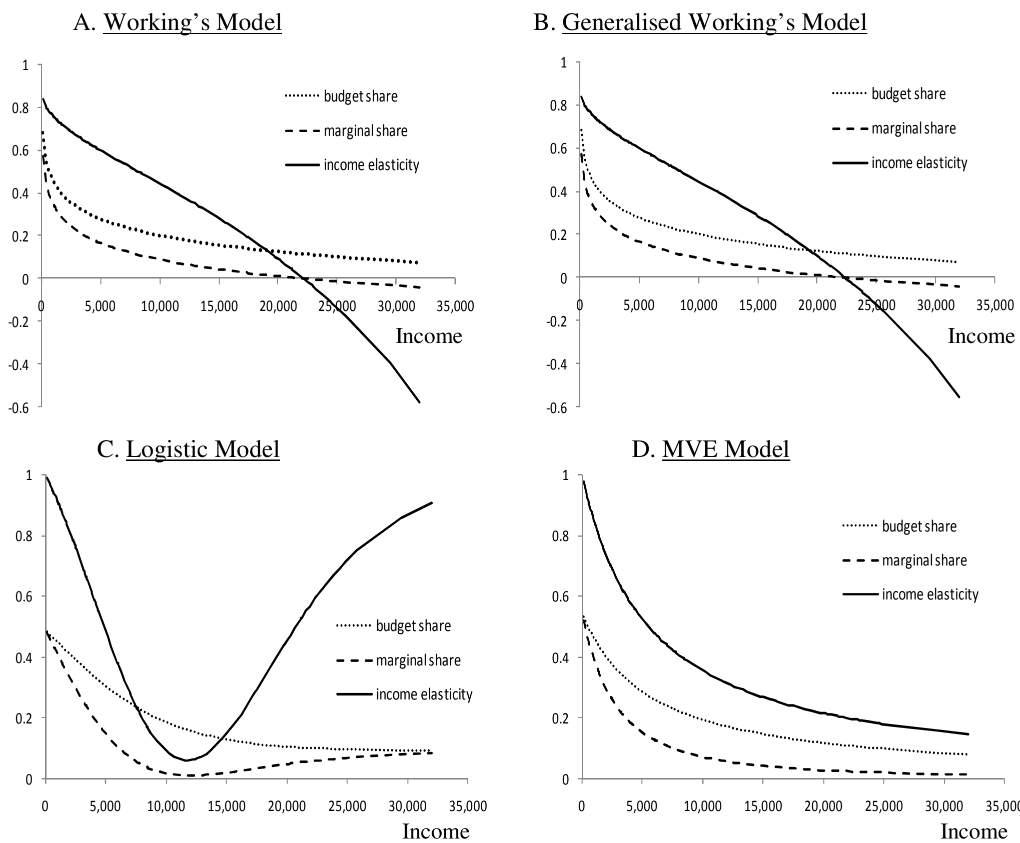
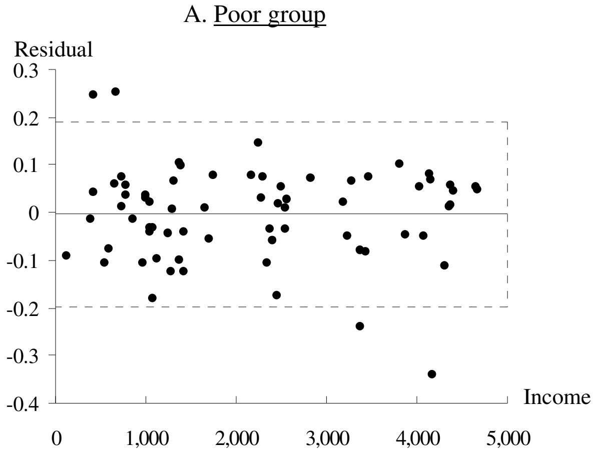
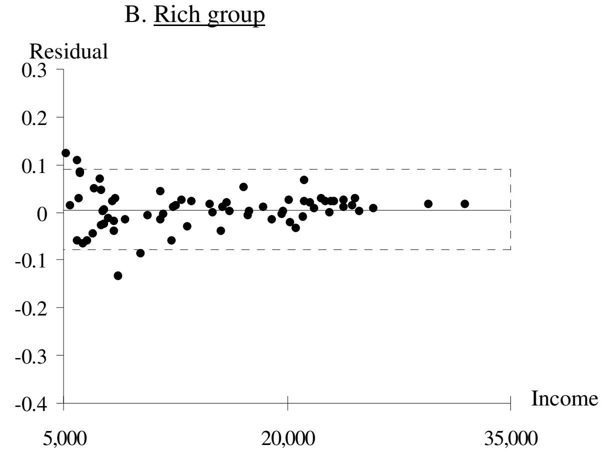


FIGURE 3.1

RESIDUALS, MVE MODEL





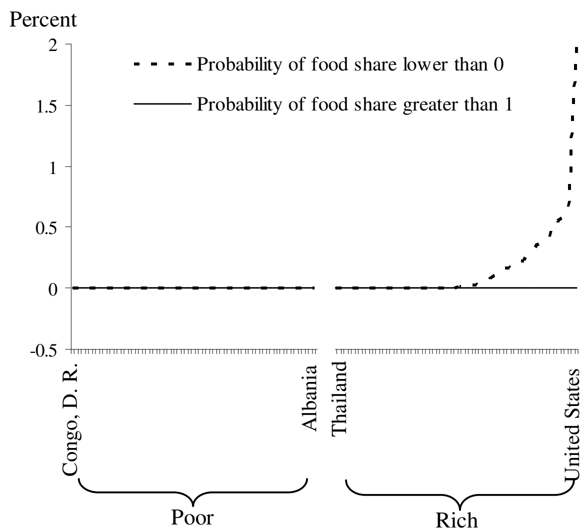
Notes: 1. The means of residuals are close to 0 (solid line) in Panel A and B. The dotted box indicates the mean ± 2 standard deviations.

2. Summary statistics of the residuals are:

	Mean	SD	Max	Min
138 countries	0.0010	0.0749	0.2518	-0.3410
Poor group	-0.0039	0.0975	0.2518	-0.3410
Rich group	0.0059	0.0418	0.1228	-0.1354

FIGURE 3.2

PROBABILITY OF PREDICTED FOOD BUDGET SHARE LYING OUTSIDE [0, 1]

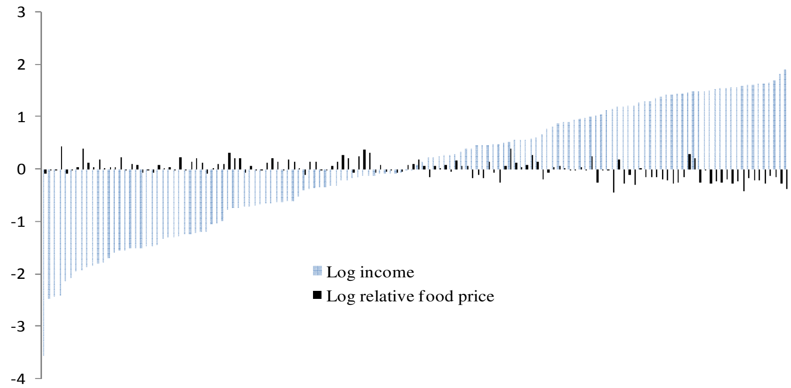


Note: 138 countries are ordered according to income.

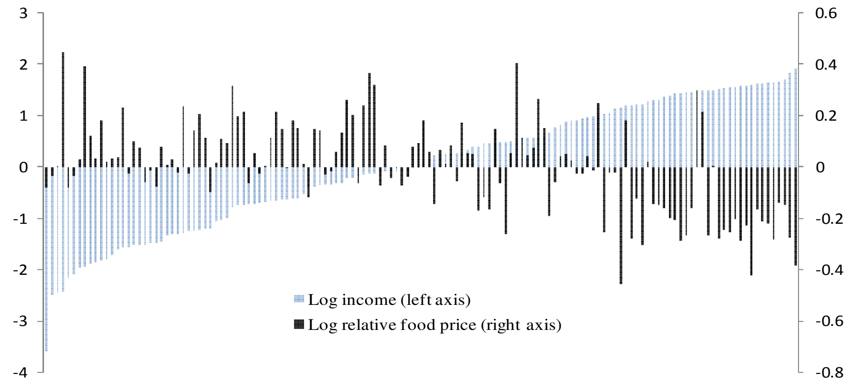
FIGURE 4.1

DISPERSION OF INCOME AND RELATIVE FOOD PRICE ACROSS 138 COUNTRIES

A. Same scales



B. Different scales

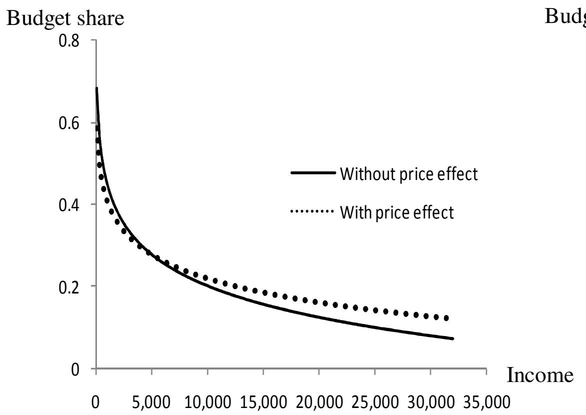


Note: Countries are ranked by income, from the poorest to the richest. The logarithm of income and the logarithmic relative price are both expressed as deviations from their respective means. The standard deviation of log income is 1.203, while that of the logarithmic relative price is 0.175.

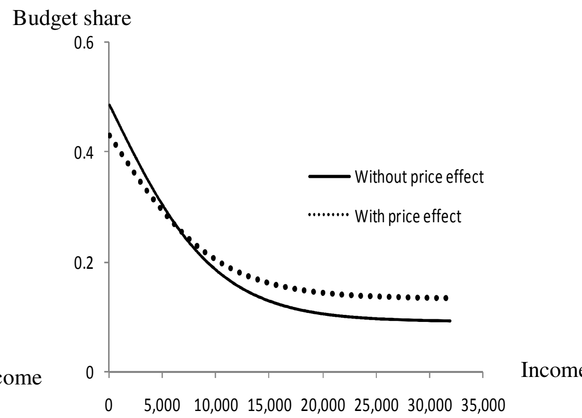
FIGURE 5.1

ENGEL CURVES FOR FOOD WITH AND WITHOUT PRICE EFFECT

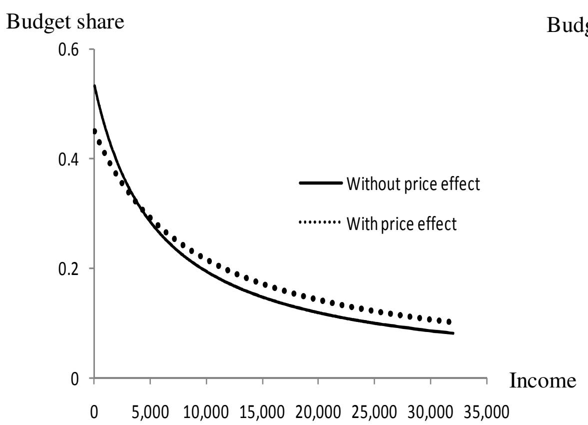
A. Working's model



B. Logistic model



C. MVE model



D. Logit MVE model

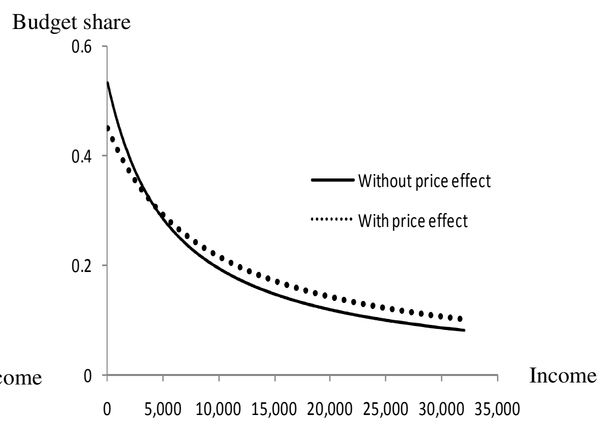
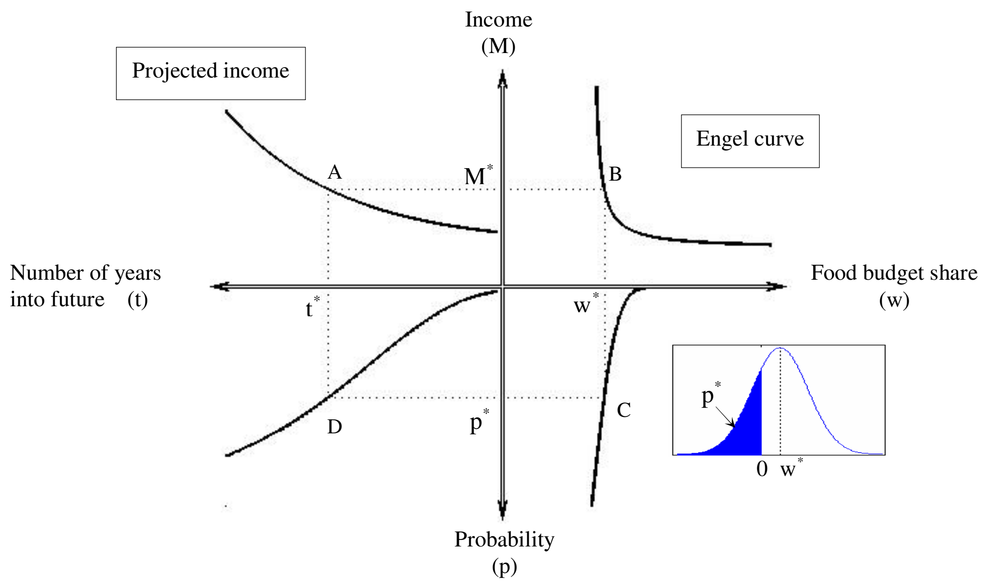


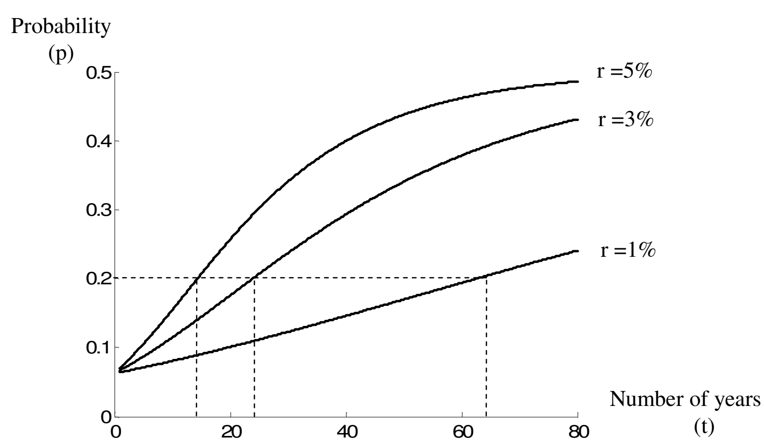
FIGURE 5.2

EXTREME VALUES OF INCOME IN US

A. Income growth and probability of negative share



B. Probability of negative share against years in future



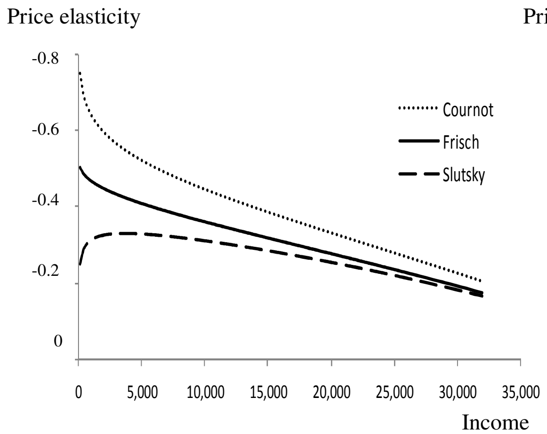
Note: The table below further illustrates the working of this figure by tabulating the number of years into the future for three growth rates, until there is a 20% chance of negative food share in the US. The elements in the last column (price effects included) are read off from panel B of the figure. The second last column (price effects excluded) is computed similarly. 95% confidence intervals are in square brackets.

$P(w<0)=20\%$ when income grows at	Price effects Excluded	Price effects Included
1% p.a.	27.9 [5.0, 46.6]	65.3 [30.9, 90.9]
3% p.a.	9.4 [1.7, 15.7]	23.0 [10.4, 30.6]
5% p.a.	5.7 [1.0, 9.5]	13.3 [6.3, 18.5]

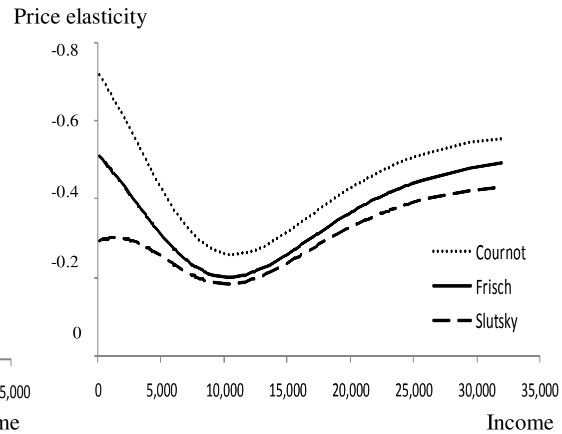
FIGURE 5.3

THREE TYPES OF PRICE ELASTICITIES OF FOOD DEMAND

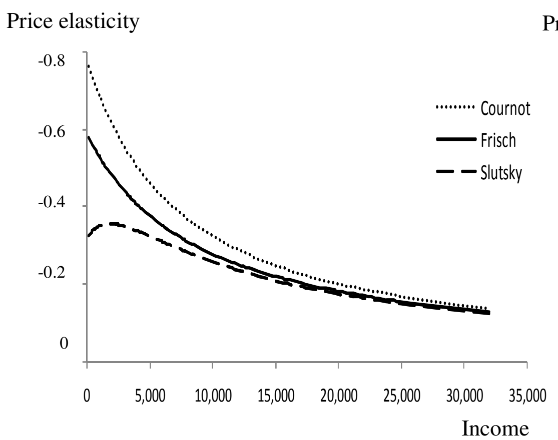
1. Working's model



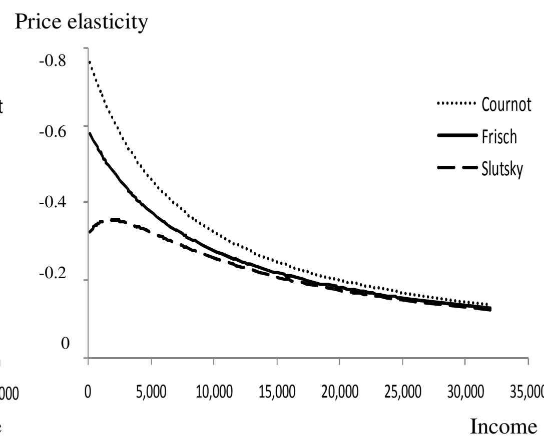
2. Logistic model



3. MVE Model



4. Logit MVE model



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