WORKING PAPER 2013:

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AgriFood economics centre

Food waste among Swedish households

much ado about nothing?

AgriFood Economics Centre Working Paper 2013:8

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Abstract

The fact that households in the OECD throw away food that is perfectly eatable has caused some debate and calls for actions to reduce such “unnecessary” waste of food have been articulated. There seems to be two primary triggers for the concern: the environment and world hunger. Our analyses show that:

- Even if the food waste could be eliminated without any cost to the households, the environmental effects would be small. However, consumers in developing countries would benefit from lower world market prices on food.
- Important reasons for food waste among households are that food is cheap, easily decays, and that the households’ time is valuable.
- The households’ waste of food could be reduced by raising the price of food.
- Raising the VAT on animal products in the EU would only reduce agriculture’s negative impact on the environment marginally. The effect on world market food prices and, hence, on consumers in developing countries, would also be limited.

1. Introduction

According to an FAO study (Gustafsson et al, 2011), roughly one third of the food produced in the world for human consumption (approximately 1.3 billion tonnes per year) is lost or wasted. Food losses occur along the whole supply chain from agriculture, postharvest handling and storage (in the case of vegetables), processing, to distribution and finally consumption.

The purpose of this paper is to analyse why food is being wasted and to discuss policies to reduce the waste. Only waste at the household level will be analysed focusing on the situation in industrialised countries, especially Sweden. Several explanations have been identified and will be critically examined. Many of them focus on information failures, for instance, consumers confusing or misinterpreting food labels. This paper instead highlights economic factors such as the impacts of incomes, relative prices and time costs using an analytical model of consumer behavior (cf. section 3).

Households in Europe and North America are estimated to waste between 95-115 kg of food a year (op cit). The high level of waste has attracted considerable attention. But why is it wrong to throw away food? Looking at the condemnations of food waste, two main reasons for the concern can be distinguished. The first relates to the environmental impact of food production, the second to the moral implications of food waste.

Regarding the environmental issue, food production requires large amounts of (increasingly) scarce resources, such as land and water, and has a negative impact on the environment. Other things equal, if no food is wasted, less needs to be produced. Then, the negative consequences for the environment, often not accounted for in food prices, would be reduced. In addition, there would be no negative environmental impacts from the disposal of food waste.

But would eliminating food waste be an efficient way of reducing agriculture's negative impact on the environment? Here, the effects of eliminating food waste will be compared to those of a tax on the consumption of animal products, which has been frequently suggested for the sake of the environment (Berglund et al., 2010; Swedish Board of Agriculture, 2012 and 2013). Both policies have a similar focus since both aim at reducing the environmental degradation caused by agricultural *production* by reducing *consumption*. However, the implications for the *structure* of consumption would be different as fruits and vegetables account for a sizable share of food waste and, hence, would be strongly affected if food waste was to be eliminated, but not at all by the tax. The comparison will be based on simulations with the CAPRI model and presented in section 4.

As to the moral issue, it is noted that food is a necessity and that some people do not have enough of it. FAO estimates that around one billion people suffer from undernourishment. Accordingly, several authors (see for instance MacMillan, 2009) argue that is immoral to throw away food. Reducing food waste may therefore be important for the issue of food security. For instance, the Commission on Sustainable Agriculture and Climate Change (Beddington et al, 2012) recently included a reduction of losses and waste in the food system as one of seven recommendations for achieving food security in the face of climate change. See also Lundqvist (2010). Stuart (2009), claims that elimination of food waste in the developed countries could result in the eradication of hunger. However, results from other studies indicate that nutritional problems are caused by low incomes in relation to food prices rather than by a shortage of food per se (see, for instance, FAO 2006 or 2012a, and the references therein). Assuming that lower waste at the commodity level would translate to lower demand for the same commodity in the EU, and taking into account the sheer size of the waste, world market prices would be likely to fall. This might benefit people with low incomes. However, lower world market prices on food may also have negative effects on the incomes of farmers in developing countries and could reduce incentives for food production. An estimation of the impact of a reduction of food wasted by consumers in the EU on world market prices, using the same model as above, is presented in section 4.

A less frequent argument, which will not be further analyzed, relates to the economic implications of the waste, in particular for the individual household. The fact that consumers choose to lose money by wasting food rather than spending it on something else should, however, not be a source of concern for others, *in addition* to the moral and environmental concerns mentioned above.

2. Data on food waste

Given the interest in the public debate, it is somewhat peculiar to find that data on food waste are scattered and rudimentary. One problem concerns how to define the concept. The United Nations' Environment Programme (UNEP), for instance, includes food which is fed to livestock and which could be consumed by humans, see FAO (2012b) for discussion. As a result, UNEP estimates that as much as 50 percent of the food produced in the world is lost, a considerably higher figure than the widely quoted FAO estimate above. An even more extreme view is to consider overeating and obesity as food waste, (Smil, 2003).

The EU defines food waste as *raw or cooked food materials discarded anytime between farm and fork* (European Commission, 2010). This is then divided further into the sub categories *Avoidable food waste* (food that is thrown away but was edible prior to disposal), *Possibly avoidable food waste* (food that some people would eat but other not, e.g. bread crusts and potato skins), and *Unavoidable food waste* (waste arising from food preparation that is not edible under normal circumstances such as bones, egg shells, pine apple skins, used teabags and coffee grinds).

The database EUROSTAT contains data on waste in the EU according to the categories; *Animal and vegetable waste* (EWC 09), *Animal waste of food preparation and products* (EWC 0911), and *Animal faeces, urine and manure* (EWC 093).[1] This can be further disaggregated according to where the waste originates; *primary production*, *manufacture*, *households*, and *other sectors* (whole- and retail sale, food services, etc.). It is noted that, since the member states (MS) are free to decide on the method of collecting data, they are not comparable across countries (European Commission, 2010).

MS have, in fact, used a wide range of methodologies for estimating food waste. The most frequent include: qualitative interviews/surveys, kitchen diaries, compositional analysis of household waste at collection point, plate examination and inferential methods. All of them suffer from drawbacks (Muth et al, 2011). For instance, respondents surveyed by telephone interviews or on-line (recall questionnaire techniques) are seldom able to give accurate estimates of the quantities wasted. Respondents asked to keep diaries over a period of time may more accurately assess how much food they actually throw away, but may alter their behaviour because they are being observed, or underreport if they feel guilty about wasting food. Compositional analysis misses liquids and foods disposed of in other ways. Plate examination is only used to assess food waste in institutions (hospitals, restaurants etc.). Inferential methods, finally, depend on the availability of appropriate databases and rely on numerous assumptions.

Moreover, studies also differ with respect to what is included: avoidable vs. unavoidable waste, home composting of waste, food to pets and domestic animals etc. Those cir-

[1] Cf. http://epp.eurostat.ec.europa.eu/portal/page/portal/eurostat/home

cumstances may explain the considerable differences in the estimates of losses that different studies have arrived at, (cf. Parfitt et al, 2010, Table 7).

Nevertheless, the European Commission has attempted to estimate the amount of food wasted in the EU by subtracting the quantities in the EWC 093 category from those in the EWC 09, i.e. by applying an inferential methodology. Table 1 presents the results for EU-27, Sweden, and the UK in 2006 (the UK is included because they have the most detailed data on food waste among households).

Table 1: Food waste in the EU, Sweden, and the UK (tonnes, 2006)

Country	Primary prod.	Manufacture	Households	Other sect.	Total	Total excl. prim. prod.
EU-27	32 636 495	37 307 575	23 351 264	16 264 345	110 116 678	77 480 183
Sweden	3 122 000	601 327	386 011	547 335	4 656 673	1 534 673
UK	22 500	5 142 864	3 244 433	3 500 092	11 909 889	11 887 389
Source: EU Commission, 2010.						

According to these estimates, there appear to be substantial differences in the distribution of food waste between the EU-27, Sweden, and the UK across sectors. This may partly be a result of structural differences between MS. Still, because of the methodological problems referred to above, the figures should be interpreted with caution. For instance, as the primary sector in Sweden is only 2.8 percent of the primary sector in the EU-27 (EUROSTAT) it is highly unlikely that waste in the Swedish primary sector should equal almost 10 percent of waste in the primary sector in the EU. Turning to food waste among households, measured in kg per capita and year, these data are presented in Table 2 along with data from national sources for Sweden and the UK.

Table 2: Food waste among households in the EU, Sweden, and the UK.

Country	Kg per capita according to EUROSTAT data for 2006[a]	Kg per capita according to national sources
EU-27	47	
Sweden	43	72[b]
UK	54	137[c]
Sources: [a)] EU Commission, 2010. [b)] SMED, 2011. [c)] WRAP, 2008 and 2010.		

The data from national sources in Sweden were generated by compositional analyses of waste collected from households in a sample of 10 municipalities in 2010,[2] which is claimed to be representative for Swedish households. Although compositional analysis misses waste of liquids, the quantities are almost twice as large as those reported for Sweden by the EU Commission. Data do not include information on quantities of waste according to type of food, or on household characteristics, which makes it difficult to

[2] Båstad, Falköping, Gävle, Helsingborg, Höganäs, Lindköping, Malmö, Sundsvall, Åstorp, and Ängelholm.

analyse what factors that affect the generation of food waste. However, they suggest that Swedes throw away about 1.4 kg of food per person each week, or about 0.2 kg per person each day. Data from national sources in the UK were generated from interviews with 2 715 households in England and Wales, followed by compositional analyses of waste from 2 138 of them. It is claimed that the selection of households is representative for households in England and Wales. The data suggest that the average Brit throws away about 2.6 kg per week, or 0.376 kg per day. They are not comparable to the Swedish data as the interviews, in principle, could generate information on waste of liquids but, on the other hand, may be subject to recollection errors.

3. Causes of food waste

Several factors might explain why households throw away food and why some throw away more than others. Hence, to structure the discussion, we utilise a model of the household's decision problem and investigate how the model's predictions fit the empirical findings.

The model presents a stylized picture of consumer behavior and is an application of the one proposed by Becker (1965), where households are assumed to derive utility from "commodities" they produce themselves by combining market goods and time (see Appendix 1 for details). Commodities may be thought of as activities such as taking a vacation, creating a garden, socialising with friends, etc. The household's problem is to allocate the use of market goods and time so as to maximise utility from the commodities produced. This requires that inputs are allocated so that the costs of producing the commodities are minimised (otherwise there would be some other allocation that produce the same amount of commodities at lower cost, implying that utility cannot be maximised). Cost-minimisation occurs when, for all commodities, the cost of producing an additional unit of that commodity is the same regardless of what input that is used.

Assume that one commodity is "meals" which are produced by combining the market good "food" with time for planning meals, purchasing food, preparing meals from the food purchased, and for preserving left-overs for later use. Waste occurs because some parts of the food are inedible ("unavoidable" waste) or because food is perishable (avoidable waste). Thus, other things equal, the more food that is purchased, the more waste is generated. As waste is food that has been paid for, it is a cost to the household. It may be reduced by using more time for planning and preparation. However, using more time in meal production also implies a cost as each unit of time has to be taken from some other use. As most people use some of their time for market work, the price of time is taken to be equal to the wage rate. Utility is maximised when the cost per unit of meal produced by using food equals the cost per unit of meal produced by using time *and* the cost per unit of any other commodity produced by using either market goods or time. One conclusion from the model is, therefore, that the waste that occurs is the result of the households' efforts to optimise utility given the prevailing conditions.

The model also generates predictions on how households will respond to changes in these conditions (food prices, food waste tariffs, wages, non-labour income etc.). These are summarised in Table 3 and discussed more fully in Appendix 1.

Table 3: Predictions of effects on food waste from changes in key parameters.

Parameter change	**Effect on food waste** (other things equal)
All food prices increase by the same amount.	Reduction in waste. Households induced to use less food and more time in meals production.
Increase in some food prices only.	Reduction in waste of foods for which prices have increased. Households induced to increase use of other foods and time. Increase in waste of foods for which prices have not increased. Total effect indeterminate.
Fee (or increase in existing fee) on food waste.	Reduction in waste if it can be measured at household level. Raising the fee increases waste costs, thereby inducing households to use more time in meals production.
Increase in market wage.	Increase in waste. Households induced to use more food and less time in meals production.
Higher non-labour income	Increase in waste. Higher non-labour incomes increases the demand for meals and, hence, the use of food in meals production.
Better knowledge in meal production.	Uncertain. Better knowledge reduces the cost of meal production. Reduction in waste if the price elasticity of meals is smaller than unity. Increase in waste if the price elasticity of meals is larger than unity.
Information on problems caused by food waste.	Reduction in waste if information reveals previously un-known private cost or welfare loss caused by waste.

The model suggests that food is wasted if it is cheap (in relation to time), tariffs on food waste are low, and, possibly, if knowledge of the problems caused by food waste is insufficient. One could, in principle, estimate the effects of changes in these parameters. However, this would require data on waste according to type of food in individual households, on food prices, and on socioeconomic characteristics for these households, which are difficult to obtain. To our knowledge, no attempt to estimate a model of this kind has been made. Economic models of food waste are usually based on assumed frequencies of waste per commodity. The household model can, therefore, only be "tested" indicatively by comparing its predictions with existing observations on food waste and with results from other types of food waste studies.

It may be of interest to start with a short presentation of the causes of food waste as *reported* by consumers. Consumer behavior with respect to food waste has been analyzed using a survey of a representative sample of 1862 households in the UK and 15 focus groups in England (Cox and Downing, 2007). Over 30 reasons for food waste were identified, most notably *buying too much*, in particular due to the temptation of special offers, *buying more perishable food*, *poor storage management*, *ad hoc cleaning of stored products*, *high sensitivity to food hygiene*, *preparing too much food*, *not liking food prepared*, *lifestyle factors* (lack of time, fluid work or social patterns, etc.). Discussion with focus groups identified four generic causes: *promotion campaigns by supermarkets*, *poor planning/poor management*, *personal choice and lifestyle* and *lack of skills*. Several other studies have reported similar reasons (cf. Koivupuro et al, 2012 for a summary and a discussion).

Some of the factors explaining food waste, such as lack of skills, are directly in accordance with the predictions of the household model. The importance of skills and experience (and time) is also confirmed by the fact that older persons seem to throw less away according to several studies (see for instance WRAP, 2008). Several causes highlighted by consumers in the surveys can be easily translated to the time requirements to prevent waste, for instance, poor storage management and preparing too much food. It is often claimed that "nobody intends to waste food from the first" (Schneider, 2008). Thus, if nobody buys food with the intention to throw it away, the observation that consumers repeatedly do so could be seen as indicating that they are aware that some of the food bought may be wasted but find it too costly to avoid this at given prices.

However, falling to temptations of special offers does not fit well with the household model's predictions. The model assumes that consumers are rational and, hence, cannot be fooled to buy more than they really want. It should be pointed out, though, that a recent study by WRAP (2011) did not find support for the claim that food waste is caused by special offers such as "buy one, get one free (BOGOF)". Although 44 percent of the shoppers think that buying food on offer leads to a greater amount being thrown away, only four percent actually wasted food bought as a part of the promotion. Moreover, (Koivupuro et al., 2012) found, in fact, an opposite effect. Consumers, who often bought discounted food products, were less likely to throw food away.

As to the impact of an increase in the price of an individual food, data from the UK and the US may be utilised. For instance, in 2008 WRAP published a study on food waste according to type of food. Data were generated from interviews with 2 715 households in England and Wales, followed by composition analyses from 2 138 of them. It is claimed that the selection of households was stratified according to economic and social variables to assure a sample that was representative. The results appear in Table 4.

Table 4: Avoidable food waste (per person and year) in England and Wales.

Type of food	**Proportion of food purchased that is thrown away (percent of value)**	**Price per kg (£)**
Salad	60.4	2.28
Fruit	36.2	1.97
Bakery	31.0	1.82
Desserts	27.2	3.81
Condiments	24.1	3.80
Vegetables	21.9	1.32
Dried food	17.8	2.66
Confectionery	16.8	5.55
Meat and fish	16.3	5.29
Dairy	9.8	2.99

Source: WRAP (2009) and own calculations (prices have been calculated from values and quantities reported in WRAP, 2009).

The food types have been ranked according to the value of waste in percent of value of purchase. The ranking seems to suggest that waste largely depends on how expensive and how perishable the food is. That is, the less expensive the food is the more of it is thrown away, and the more perishable the food is the more of it is thrown away. The exception is dairy products which, though being neither the most expensive nor the least perishable, display the smallest share of avoidable waste per person. However, it is possible that waste of dairy products has been underestimated since liquids, which constitute a considerable part of dairy products, may be missed by some estimation methods (compare above).

Table 5 presents data on food waste for the US. Here, food types are ranked according to their wastes' respective shares in consumption. Direct comparison of tables 4 and 5 is hardly meaningful as different methodologies have been used for estimation of the waste. Venkat (2011) uses data from USDA, which are based on inferential methods complemented with expert judgments, whereas the WRAP data are based on direct measurement of quantities wasted and personal interviews. However, in a broad perspective, the USDA data also suggests that price and perishability seem to constitute an important explanation of the waste which fits quite nicely with the predictions of the household model.

Table 5: Share of avoidable food waste in US's food consumption

Type of food	**Share of avoidable waste in consumption**[a] **(percent of consumption)**	**Value of avoidable consumer waste per kg** **$**
Vegetables	40	3.7
Fruits and juices	32	2.7
Pork	31	9.2
Chicken	31	6.0
Grains	26	2.1
Sweeteners	25	3.4
Milk and yogurt	25	1.9
Other diary	22	5.3
Fish and shellfish	19	17.7
Cheese	16	10.3
Beef	14	9.8
Eggs	14	0.9
Butter and fats and oils	12	4.5
Nuts	11	14.0
Other meats	11	11.4
Legumes	11	5.0

[a)] We interpret consumption as amounts purchased, i.e. not as amounts actually "eaten" by the household.
Source: Venkat 2011, Tables 2 and 4, own calculations

The household model predicts that higher incomes results in higher waste. A positive correlation between food waste (and waste in general) and income is confirmed both by general observations and by several studies. According to a survey of older studies, by Parfitt et al (2010), between 1 and 3 percent of all food was wasted in Britain before the Second World War. This share had increased to between 5.6 and 6.5 percent in 1980 and to about 25 percent in 2008. Even if the figures can hardly be compared directly, they suggest that waste has increased over time along with incomes. This connection between waste and income is also consistent with the fact that, seen over the whole food chain, food losses are distributed differently in developing and industrialized countries. In the former, losses occur at post-harvest and processing levels (due to unavailability of proper technologies) while in industrialized countries, more than 40 percent of the losses occur at the retail and consumer levels (Gustafsson et al., 2011).

An Australian study (online survey of 1 603 grocery buyers) found that household income has a strong influence on the amount of food wasted (Baker et al., 2009). Skourides et al. (2008) found, based on a compositional analysis of food waste generated by rural and urban households, that the quantity of waste was influenced by, inter alia, income (using the size of the house as a proxy for income). A study by Koivupuro et al (2012) of 420 Finnish households keeping food waste diaries found, on the other hand, no correlation between household income and food waste. However, the households only reported to which income category they belonged, which may be to crude a measure. Wenlock et al (1980) found that, with few exceptions, differences in income did not significantly affect the total amount of food wasted. Wasserman and Schneider found, based on interviews, that people with full time jobs waste more food. Schneider (2008) interprets this as a result of higher income and a lack of time.

Higher fees for waste collection are predicted by the model to reduce food waste. Food waste is collected together with other household waste. A review of the international literature on pay-by-use collection systems of waste by O`Callaghan et al (2009) indicate that volume-based systems were least effective in reducing waste to landfill/incineration while tag-based systems and weight-based systems had much greater success in reducing unsorted waste. Tag-based systems (only bags with tags, which have to be purchased by households, are collected) and weight-based systems (households paying per kg of waste) create a stronger link between the quantity of waste and the cost for the households than volume-based systems that rely on an annual charge.

Accordingly, it may be concluded that results from empirical studies do not refute the predictions of the household model.

4. Potential gains from decreasing food waste

Modelling market equilibrium with waste elimination

According to the Becker household model food waste is the result of rational decisions. Thus, there is no way of getting rid of it without a cost, since the consumer must be made to act in a way that she would not do voluntarily. Nevertheless, it is interesting to analyse what would happen *if* waste could be "magically" removed. Doing so would provide an (optimistic) estimate of the potential gains from removing waste, or conversely, how big the impact of food waste on various indicators of interest might be.

The effect of reducing food waste on the demand for food will generally be lower than what is implied by a simple back-of-the-envelope calculation of "demand times loss rate", due to something called *rebound effects*. The problem of reducing food waste has strong similarities with the more rigorously studied subject of energy efficiency. In energy efficiency studies, the rebound effects of increasing energy efficiency are categorized as *direct effects* and *indirect effects*, sometimes also *economy wide effects* (Greening, et al., 2000). The direct effects are caused by the real price reduction following higher efficiency in use, when less energy needs to be purchased in order to achieve the same outcome. In theory, the effect of lower real prices can be further decomposed into *price* or *substitution effects* and *income effects* (as in the household model). Indirect effects relate to various other effects, including the effects in other sectors due to market price changes resulting from changes in energy demand, effects of changed cost of production of energy-intense products, and changes provoked by the increase in GDP following higher energy efficiency. If the rebound effect is greater than the initial efficiency gain, total consumption increases. Such an outcome is called *backfire*.

A reduction of food waste is similar to an *increase of the efficiency* in food utilisation and, therefore, rebound effects will occur. The partial equilibrium model that we use for the simulations allows us to capture, apart from the immediate technical effect of reducing food purchases, also substitution and income effects. Furthermore, the market price will respond to demand changes, letting us compute also secondary effects working via the market price. We are not able to capture the general equilibrium effects working over factor markets, the effect on food processing industry, or the effect caused by the fact that food waste itself might be an input in other industries (such as biogas production and garbage collection), the prices of which might change in turn.

We use the so called CAPRI model (Britz & Witzke, 2008) to simulate the impacts of food waste on commodity markets and agricultural production, and to derive results for agricultural income, consumer welfare, greenhouse gas (GHG) emissions and soil nutrient pressures. CAPRI is a comparative static partial equilibrium model for the agricultural sector of the EU developed for impact assessment of the CAP and trade policies from global to regional scale. It is solved by iteratively linking its supply and market modules. The market module is a global spatial multi-commodity-model using 28 trade blocs and 60 countries. Based on the Armington approach (Armington, 1969), products are differentiated by origin, enabling bilateral trade flows and the explicit implementation of bilateral as well as multilateral trade instruments.

The supply module is composed of separate, regional, non-linear programming models. These are based on assumed profit-maximizing behaviour under technological constraints, most importantly in animal feeding and fertilization, but also constraints on inputs and outputs such as young animals, land balances, and set-asides. In addition, the regional models contain econometrically estimated behavioural functions (Jansson & Heckelei, 2011). The supply module currently covers all MS within EU-27, as well as Norway, Turkey and the Western Balkans broken down to about 280 administrative regions (Nomenclature of Territorial Units for Statistics (NUTS) II level) and more than 50 agricultural products. CAPRI has been much employed in applied policy impact analyses (see project website www.capri-model.org for an updated list) in the EU as it implements both as a regionalized agricultural supply model with detailed production technology and a world trade model for agricultural and food commodities.

In order to implement changes in food waste in the CAPRI demand system, we need to conjecture a theoretical model of the household including food waste that is amenable to numerical analysis. We opt for the following model, where waste is of no use to the consumer and, in contrast to in the household model, constitutes a fixed share (ψ_i) of purchases of each food (X_i). Denoting the *reduction in food waste* as r_i, we can write the degree of food utilisation (α_i) as $\alpha_i = 1 - \psi_i + r_i$, and assume that the consumer acts as if maximizing utility U derived from (loss-free) consumption, subject to market prices P_i and a total income (i.e. $Y + \omega T_\omega$) equal to M:

$$\max U(X_1\alpha_1,\dots\dots, X_n\alpha_n) : \sum_{i=1}^{n} P_i X_i - M = 0 \quad (1)$$

CAPRI's demand system is derived from an indirect utility function using the semi-flexible form called "Generalized Leontief" (Ryan & Wales, 1999). As there is no direct utility function available, modelling changed food waste rates is not as straightforward as in the equation above; the food utilization rate a_i will be implicit in the parameters of the GL function. We may nevertheless derive the impact of changing waste reduction r_i as an approximation by writing the indirect utility function associated with the direct utility maximization problem above in two equivalent forms, where the second function $v^*(P, Y)$ is obtained from the first by substituting ξ_i for ($X_i \times a_i$) and π_i for (P_i/a_i).

$$v(P_1,\dots\dots, P_n, Y, \alpha_i,\dots\dots, \alpha_n) = \left\{ \max U(X_1\alpha_1,\dots\dots, X_n\alpha_n) : \sum_{i=1}^{n} P_1 X_1 - M = 0 \right\} \quad (2)$$

$$v^*\{\pi_1(P_1, \alpha_1),\dots\dots, \pi_n(P_n, \alpha_n)\} = \left\{ \max U(\xi_1,\dots\dots, \xi_n) : \sum_{i=1}^{n} \pi_i(P_i, \alpha_i)\xi_i - M = 0 \right\} \quad (3)$$

The function $v^*(P, M)$ contains the parameter a in a directly accessible form in the function $\pi_i(P_i, a_i) = P_i/a_i$ (a scaling of prices), and can be used to analytically derive the impact of reducing food waste on *net* consumption, $\partial\xi_i / \partial r_i$, making use of Roy's identity. Using the equivalence and some derivations, the result can be expressed in terms of derivatives of the first function *v*(*P, M*), for which we *do* have parameter estimates. In that way we obtain a first order approximation of the effect of reducing waste, disaggregated in terms of a "technical effect" of just not purchasing the waste, a "direct income effect" (the household can spend the money saved on any good), and a "direct price effect" (the real price of net consumption, π, has been reduced). The derivations are presented in detail in Appendix 2.

The following table lists the various ways in which food waste elimination can be expected to influence household food consumption. In the computations reported in this research, we consider the technical effect, the direct price and income effects, the indirect own price effect and part of the indirect income effect (the part due to changed market prices of food, but not the income effect of changed prices of everything else).

Table 6: Expected effects on food consumption of eliminating food waste

Term	Description	Direction of change
Technical effect	The initial effect of reducing food waste. The consumer simply does not buy "waste" anymore, so consumption decreases.	–
Direct price effect	Food purchases include "food actually consumed" + "waste", in fixed propotions. The effective price of "food actually consumed" decreases when consumers no longer need to buy "waste", making food more attractive relative to other goods.	+
Direct income effect	When the consumer no longer needs to buy waste, the budget available for spending on all goods including food increases.	+
Indirect own price effect	The market price of food will react to changes in demand. More precisely, demand for food is likely to decline initially (due to the technical effect), thereby reducing food prices which, in turn, stimulates demand for food.	+
Indirect cross price effects	Other sectors consuming food (such as certain services, like restaurants and hotels) will benefit from lower market food prices too, lowering their input costs, and marginally lowering their output prices. It seems likely that demand for food by other sectors will tend to increase, unless the reduction in food prices is such that the final demand for other sectors' output by the consumer is reduced (as the price ratio food/other shifts in favour of food)	?
Indirect income effects	When all market prices change, the total expenditure of the consumer changes too, influencing consumption patterns. If food is a normal good, additional income will tend to increase consumption.	+
Other effects	A multitude of other changes will occur, such as factor market changes (food sector labour use), production of by-products (bio gas, district heating from waste), need for municipality services related to waste handling, with net effects that are difficult to disentangle without a General Equilibrium model.	?

In order to isolate the effect of eliminating food waste, results are evaluated against a reference scenario that implies continuing with the currently decided ("Health Check") agricultural policies up to 2020, and not changing waste rates. Against that baseline we then analyse the effect of also reducing food waste rates. We used the information in Table 5 above provided by (Venkat, 2011) to define the technical change Δr_i for each good i in CAPRI, by selecting the waste rate for the good in Table 5 deemed to be the most similar to those included in the CAPRI-model.

Market equilibrium with a tax on the consumption of animal products

Eliminating food waste as by a strike of the magic wand is certainly utopic. As a contrast, we analyse the effects of levying an extra consumption tax on a sub set of animal products in proportion to the GHG emissions caused by their production.

As the quantitative results are produced by a model with fixed waste coefficients (i.e. $\psi_i = \beta \times X_i$), the tax works only via changed consumption patterns. Accordingly, the conclusions from the analysis of the household model with endogenous waste rates that depend on the household's allocation of time to various activities suggest that the simulation results for the tax on animal products underestimate the impacts on demand.

In order to trace out the effects of the tax, we assume a consumption tax of € 1 per kg of beef, and for selected other meat (red) and dairy products in proportion to the ratio of their estimated GHG emissions to those caused by beef. The resulting taxes per kg of product are shown in Table 7. The beef tax rate was chosen based on very simple considerations: It is a round number that is sufficiently high to cover historically recorded carbon emission certificate prices. Given that GHG emissions are about 10-15 kg CO_2-equivalents per kg beef,[3] this implies a carbon emission price of 100-150 euro per tonne of CO_2. It is acknowledged that this is well above the current (5 euro/t) and historical EU carbon emission prices in the ETS-system, however, it does correspond to the current Swedish CO_2-tax on fossil fuels in transportation (Skatteverket, 2013).

Table 7: Absolute tax rates (€ per kg of product) on the respective animal products.

Animal product	Tax
Beef	1.000
Pork	0.158
Sheep and goat meat	1.234
Eggs	0.047
Poultry meat	0.052
Butter	0.963
Skimmed milk powder	0.210
Cheese	0.424
Fresh milk products	0.060
Cream	0.352
Concentrated milk	0.127
Whole milk powder	0.483
Casein	0.498
Whey powder	0.073

[3] Accounting for methane emissions of around 350 kg/ton and indirect dinitrous oxide of around 15 kg/ton estimated in CAPRI based on IPCC tier one and an IO model of agriculture (Pérez Domínguez, et al., 2009) (Jansson, et al., 2010), with weights of 21 and 310 CO_2-equivalents per unit of methane and dinitrous oxide respectively. The exact numbers computed in the model depend on the region studies, since production mixes, technologies and physical conditions differ.

Simulation results – elimination of food waste versus a tax on animal products

Table 8a shows the impacts on demand as difference (1000 tonnes) to the reference demand when completely eliminating food waste. The column "demand change", shows the net change in equilibrium demand for the respective foods when all prices have adapted. The column "demand shock" shows the direct effect on demand caused by the elimination of food waste. The final three columns explain this direct effect as the net of a technical effect (higher efficiency in food utilisation), a direct income effect, and a direct price effect of eliminating waste. The difference between the columns "demand shock" and "demand change", finally, is that the demand column also accounts for some of the indirect price and income effects resulting from the shock (cf. Table 6 above).

Table 8a: Changes in food demand in the EU-27 resulting from eliminating household food waste (1000 tonnes difference to reference).

Product	Reference	Demand change	Demand shock	Technical effect	Income effect	Price effect
Cereals	67 387	-10 619	-11 355	-17 693	2 536	3 801
Oilseeds	1 196	-164	-147	-141	42	-49
Other arable field crops	35 041	-5 345	-5 430	-6 931	1 275	226
Vegetables and Permanent crops	116 250	-18 176	-22 147	-27 999	4 423	1 429
Meat	43 183	-6 269	-7 098	-12 085	1 574	3 412
Other Animal products	6 854	-867	-897	-962	249	-184
Dairy products	65 113	-15 624	-13 054	-18 991	2 842	3 095
Oils	9 227	-853	-884	-1 112	340	-112
Oil cakes	634	-56	-59	-76	21	-4
Secondary products	23 329	-4 285	-4 121	-4 845	690	33

The results indicate that, despite considerable rebound effects, the purely technical effect is the dominating component in the demand shock. Thus, the elimination of food waste leads to most significant reductions in food demand in the EU. The reduction in demand pertains to all foods but most strongly to items that are prone to losses and have low price and income elasticities (as manifested in the price and income effects), such as dairy products and secondary products (sugar).

When levying a tax on animal products, the effects on demand completely originates from the price and income effects of the tax (i.e. there is no "technical effect"). It therefore tends to reduce demand for beef, sheep and goat meat, pork and dairy, whereas demand for most crops except cereals increase. To facilitate comparison of the effects of the tax with those of a complete waste elimination, the results are converted to percentage changes relative to the reference in table 8b below.

In the Waste Elimination scenario, the demand for dairy products is most strongly affected, with a reduction of 24 percent. However, also demand for major primary commodities such as meat, cereals and fruit and vegetables is reduced by 15 percent or more. Of the meats modelled, demand for poultry meat is more affected than other meats because of the higher loss rates in that market. The effects of the tax are much smaller in comparison. That should not be surprising, since most consumers spend only a minor share of their budget on food, and elasticities of demand are low. Demand for beef is reduced by 3 percent, pork by about 1 percent, sheep and goat meat by 4.5 percent, and milk demand by 1.5 percent. Poultry is the least taxed meat, and there demand increases due to the cross price effect of poultry becoming relatively cheaper.

Table 8b: Percentage changes in food demand (purchase) and amounts eaten in the EU-27 resulting from complete waste elimination and a tax on animal products.

	Purchase Ref	**Purchase WE**	**Purchase Tax**	**Eating Ref**	**Eating WE**
Cereals	67 387	-15.8 %	-0.2 %	49 866	13.8 %
Oilseeds	1 196	-13.7 %	0.3 %	1 053	-2.0 %
Other arable field crops	35 041	-15.3 %	0.1 %	28 120	5.6 %
Vegetables and Permanent crops	116 250	-15.6 %	0.1 %	89 099	10.1 %
Meat	43 183	-14.5 %	-1.2 %	31 314	17.9 %
- Beef	7 624	-9.4 %	-3.0 %	6 557	5.3 %
- Pork	21 818	-13.5 %	-1.2 %	15 055	25.4 %
- Sheep & goat	1 107	-14.3 %	-4.5 %	985	-3.7 %
- Poultry	12 633	-19.4 %	0.3 %	8 717	16.8 %
Other Animal products	6 854	-12.6 %	-0.1 %	5 894	1.6 %
Dairy products	65 113	-24.0 %	-1.5 %	50 040	-1.1 %
Oils	9 227	-9.2 %	0.1 %	8 120	3.1 %
Oil cakes	634	-8.8 %	0.1 %	558	3.6 %
Secondary products	23 329	-18.4 %	0.1 %	17 467	9.0 %

Notes: The first three columns show the demand changes, i.e. how much households purchase. The last two columns show changes in what households actually eat by subtracting the waste rates from the amounts purchased. Since constant waste rates are assumed in the tax scenario, the changes in "eating" in that scenario are indistinguishable from the changes in purchases.

The two scenarios also have different implications for the amounts actually consumed (eaten). In the Waste Elimination scenario, households eat more of most commodities for which waste rates were high. Meat is up by 10 percent lead by pork where it increases by a whopping 25 percent. Actual consumption of cereals, fruit and vegetables, and secondary products also increase. This is the result of the increased efficiency in consumption. In contrast, since levying a tax on animal products does not result in any technical effect, the relative changes in quantities actually consumed are identical to the relative changes in demand (quantities purchased) in the Tax scenario. Here, there will also be some substitution of vegetables for meat and the largest effects on actual consumption occur for the meat products that are taxed the most; Sheep and goat meat, Beef, and Dairy products.

The two scenarios will also affect food prices (Table 9 below). As Waste Elimination reduces demand for all foods, all food prices will fall. The relative fall in producer price is larger than that in consumer price. The reason is that, due to the wedge between producer and consumer prices caused by the (increasing) marginal costs in transportation and in food processing, a reduction in demand results in larger relative fall in the lower producer prices, than in the higher consumer prices, even if the absolute fall in consumer prices is larger than the absolute fall in producer prices. This also implies that the Waste Elimination scenario leaves consumers better off and producers worse off. In the Tax scenario, since demand is less elastic than supply, consumers will carry the larger share of the tax. For beef, for instance, the € 1 tax per kg results in an increase in consumer price of almost € 0.8 per kg (80 percent of the tax), whereas the producer price falls by about € 0.23 per kg (23 percent of the tax) and a similar pattern can be seen for the other foods. This scenario, then, leaves both consumers and producers worse off. The largest effect on prices occurs for "Sheep and goat meat" which is the animal products that is taxed the most (cf. Table 7). The ranking of the remaining animal products also follow their ranking in terms of taxation quite well.

Table 9: Effects on prices from waste elimination and tax on animal products in EU-27 (€ per kg).

	P_P Reference	P_C Reference	P_P WE €	(% diff.)	P_C WE €	(% diff.)	P_P Tax €	(% diff.)	P_C Tax €	(% diff.)
Cereals	0.144	2.595	0.135	(-6.3)	2.541	(-2.1)	0.144	(0.0)	2.596	(+0.04)
Oilseeds	0.321	1.083	0.311	(-3.1)	1.073	(-0.9)	0.320	(-0.3)	1.082	(-0.09)
Other arable field crops	0.183	0.946	0.166	(-9.2)	0.929	(-1.8)	0.183	(0.0)	0.946	(0.0)
Vegetabl. and Perm. crops	0.676	1.984	0.548	(-18.9)	1.872	(-5.6)	0.676	(0.0)	1.984	(0.0)
Meat	2.042	5.778	1.750	(-14.3)	5.425	(-6.1)	1.982	(-3.0)	6.020	(+4.2)
- Beef	3.913	8.230	3.269	(-16.5)	7.604	(-7.6)	3.688	(-5.8)	9.029	(+9.7)
- Pork meat	1.481	5.230	1.275	(-13.9)	4.988	(-4.6)	1.460	(-1.4)	5.374	(+2.8)
- Sheep and goat meat	5.572	6.881	4.758	(-14.6)	6.435	(-6.5)	5.283	(-5.2)	7.987	(+16.1)
- Poultry meat	1.678	5.147	1.421	(-15.3)	4.663	(-9.4)	1.679	(+0.05)	5.199	(+1.0)
Other Animal products	0.308	2.731	0.208	(-32.5)	2.655	(-2.8)	0.296	(-3.9)	2.776	(+1.6)
- Raw milk	0.283	NA	0.184	(-34.9)	NA		0.270	(-4.6)	NA	
- Eggs	0.804	2.731	0.718	(-10.7)	2.655	(-2.8)	0.800	(-0.5)	2.776	(+1.6)
Dairy products	1.226	1.724	1.090	(-11.1)	1.606	(-6.8)	1.191	(-2.9)	1.836	(+6.5)
Oils	1.254	4.484	1.108	(-11.6)	4.305	(-4.0)	1.253	(-0.08)	4.481	(-0.07)
Oil cakes	0.292	1.987	0.262	(-10.3)	1.960	(-1.4)	0.286	(-2.1)	1.982	(-0.3)
Secondary products	0.446	6.705	0. 401	(-10.1)	6.720	(+0.2)	0.446	(0.0)	6.705	(0.0)

Notes: P_P is Producer Price, P_C is Consumer Price. Reference, WE (Waste Elimination), and Tax are the scenarios. Raw milk has no consumer price because it is used only by dairies.

In both scenarios, the reduction in demand also affects production and trade. Imports of all commodities fall, and exports of almost all commodities rise. A new market balance is reached where the reduction in production is smaller in both absolute and relative terms. In the Waste Elimination scenario (Table 10a), production of eggs, poultry and dairy products is most strongly affected, with reductions of more than 10 percent. Beef production is reduced by about four percent. Production of crops is less affected. A secondary market effect affecting the cereals and oilseeds markets is that the demand for animal feed is reduced. For cereals, the reduction in feed demand is of similar size as the reduction in human consumption which adds to the reduction in total demand in those markets. However, cereals and oil seeds are much traded, and much of the demand reduction is absorbed by changes in trade, resulting in a net production reduction of only a few percent. Also for fruit and vegetables, trade absorbs most of the shock, leaving a net reduction in production of just three percent. In the Tax scenario (Table 10b), we see that about half of the reduction in consumption maps into production changes, the rest of the shock being absorbed mainly via a reduction of imports.

Table 10a: Changes in market balances (percent of reference) in EU-27 due to elimination of food waste

	Net prod.	Human cons. plus losses	Processing	Biofuels proc.	Feed use	Intervention stock change	Imports	Exports
Cereals	-3.5%	-15.8%	6.9%	0.8%	-7.7%	1 348.1%	-17.1%	11.3%
Oilseeds	-1.2%	-13.7%	-1.7%		-10.4%		-4.4%	-0.6%
Other arable field crops	-5.5%	-15.3%	23.6%		-4.9%		-15.0%	8.9%
Vegetables and Permanent crops	-2.3%	-15.6%	17.1%	-14.9%	17.0%		-51.6%	27.1%
Beef	-4.4%	-9.4%			-0.2%		-26.6%	41.0%
Pork meat	-7.6%	-13.5%	0.0%		0.2%		-15.0%	40.3%
Sheep and goat meat	-3.6%	-14.3%	0.0%				-5.7%	112.6%
Poultry meat	-12.7%	-19.4%					-20.0%	84.4%
Eggs	-10.1%	-12.6%	18.2%		0.2%		-40.1%	22.5%
Dairy products	-18.6%	-24.0%	50.5%		-84.3%		-27.1%	61.4%
Oils	-1.4%	-9.2%	4.9%	-0.1%	-23.8%		-4.5%	8.0%
Oil cakes	-1.9%	-8.8%	10.2%		-5.7%		-8.9%	-4.8%
Secondary products	-0.2%	-18.4%	9.0%	3.8%	2.3%		-24.1%	110.3%

Table 10b: Changes in market balances (percent of reference) in EU-27 due to the tax an animal products

	Net prod.	Human cons. plus losses	Processing	Biofuels proc.	Feed use	Intervention stock change	Imports	Exports
Cereals	-0.2%	-0.2%	0.5%	0.0%	-0.8%	52.9%	-1.4%	0.7%
Oilseeds	0.0%	0.3%	-0.3%		-0.8%		-0.7%	0.0%
Other arable field crops	0.0%	0.1%	-0.1%		-1.7%		-0.7%	0.6%
Vegetables and Permanent crops	0.0%	0.1%	-0.1%	-0.1%	-0.6%		0.4%	-0.1%
Beef	-1.6%	-3.0%			-0.1%		-8.2%	11.7%
Pork meat	-0.7%	-1.2%	0.0%		0.2%		-4.3%	2.6%
Sheep and goat meat	-1.2%	-4.5%	0.0%				-1.5%	35.8%
Poultry meat	0.3%	0.3%					0.6%	-0.9%
Eggs	0.0%	-0.1%	0.6%		0.0%		-3.2%	0.5%
Dairy products	-1.0%	-1.5%	6.7%		1.1%		-17.3%	1.9%
Oils	-0.1%	0.1%	0.1%	0.0%	-8.1%		-0.2%	0.5%
Oil cakes	-0.3%	0.1%	1.8%		-1.3%		-2.0%	-0.4%
Secondary products	0.0%	0.1%	0.0%	0.0%	-2.4%		0.2%	-0.3%

When production of most agricultural goods is reduced, externalities caused by that production – positive or negative – are also reduced. We chose to look at two impacts that are technically fairly straightforward to analyse: GHG emissions and nutrient surpluses.

Agriculture is a significant source for emissions of the two important GHG's: methane and nitrous dioxide. By multiplying the estimated emission coefficients[4] for the various goods in the model with production quantities, and converting the results to carbon dioxide (CO_2) equivalents[5] the aggregated impact on GHG emissions can be computed. For the Waste Elimination scenario, the results in Table 11 show that the reduced demand for the different types of food reported in Table 8a reduces GHG emissions by 16 million tonnes CO_2 eqv. annually in EU-27, and three times that amount in the world as a whole, which suggests that there is a "positive emission leakage" involved (i.e. that a significant part of the food wasted by EU households is imported from and, therefore resulting in GHG emissions in, "the rest of the world"). Nevertheless, it represents only about 0.3 percent of the estimated emissions for the OECD-countries in 2011 (which do not include countries such as China, India, and Russia that also contributes substantially to world emission).[6]

Table 11: Impact on greenhouse gas emissions in EU-27 (1000 tonnes annually)

Region	Elimination of food waste	Tax on animal products
EU-27	– 16 385	– 2 814
World	– 49 829	– 7 772

Imposing a tax on animal products means that demand shifts away from some of the goods that cause large GHG-emissions (cf. Table 8b). As a result, total emissions from agriculture in EU-27 are reduced by about 2.8 million tonnes of CO_2 eqv. annually. Worldwide, the annual reduction is nearly 8 million tonnes, or about 0.05 percent of the estimated GHG-emissions in the OECD-countries for 2011. Put differently, about 16 percent of the reduction resulting from complete elimination of waste could be achieved by imposing the tax on animal products in the EU-27.

Agriculture also involves large flows of various crop nutrients. We focus on nitrogen, because it is a major (macro) nutrient that can cause environmental problems if present in great surpluses, by washing out to water bodies or by changing the nature of the local environment with respect to vegetation and biodiversity. Nitrogen is added to the soil in the form of fertilizer, manure, biological fixation or atmospheric deposition, and removed from soil by harvest, gas exchange with the atmosphere, run-off, and washing out. The CAPRI model estimates nitrogen surplus as the net of all of those positions except for washing out. The surplus thus computed is an indicator of environmental impact. Results are shown in Table 12. "Surplus total" in the last row in the column for the

[4] CAPRI applies a regionalized process-based estimation of emissions compatible with IPCC methodology for EU regions, and use statistical estimates per kg of commodity for rest of the world.
[5] By applying conversion factors for methane of 21 and nitrous dioxide of 310.
[6] See the web page: http://stats.oecd.org/Index.aspx?QueryId=27912

reference scenario measures nitrate in excess of plant needs. That figure is obtained by summing the quantities in rows 2 – 6 (showing how much nitrogen that is added to the land from different sources) and then subtracting the quantity in row 7 (which shows how much nitrogen is retained by the growing plants).

Table 12: Nitrate balances for EU-27 (1000 tonnes)

	Reference	Waste Elimination	Meat Tax
Import by mineral fertilizer	11 365	-177	12
Import by manure	9 379	-466	-79
Import by crop residues	6 117	-103	-13
Biological fixation	1 067	-11	-3
Atmospheric deposition	2 138	-18	-1
Nutrient retention by crops	18 826	-412	-39
Surplus total	11 238	-365	-46

As a result of reduced overall agricultural production, elimination of food waste leads to a reduction of the total nitrogen surplus (measured as total weight of nitrate equivalent) of 365 000 tonnes pure nutrient annually in EU-27 (about 3 percent of the annual surplus in the reference). The tax on consumption of animal products leads to a much smaller reduction of 46 000 tonnes annually, or about 0.4 percent of the annual reference surplus in EU-27. The underlying mechanism in the tax scenario is the reduction in agricultural land use from lower demand for animal feed caused by the reduced demand for animal products.

As noted above, the Waste Elimination scenario has strong impacts on the economic welfare of various agents. Consumers are better off because the elimination of waste is assumed to be brought about by an increase in the efficiency in consumption that occurs without costs (the technical effect), and producers are worse off because of reduced demand. Processing industry and tax payers can also be affected due to the changes in prices, trade flows and subsidy payments. The net effect on all agents in a particular region depends on the specialization and net trade position of that region. If consumers demand commodities for which food waste was large, they will benefit much from the waste elimination. Producers of products for which waste was large, and for which the trading possibilities are limited, will lose substantial amounts because prices are strongly affected as demand falls. If a region is a net importer of a commodity that becomes cheaper, such as is the case for many products in e.g. Sweden and the UK, then consumer gains tend to outweigh producer losses. In net exporters, such as Spain (exporting lots of fruit and vegetables), on the other hand, the losses to producers will outweigh the gains to consumers.

In our simulations, imported goods are modelled as imperfect substitutes to domestic ones. Some goods, such as cereals, are fairly homogeneous, with good substitutability. Other, such as fruit and vegetables, are heterogeneous, meaning that relative prices of domestic to imported goods can change strongly without affecting market shares. If final demand in such a market is reduced, as is the case when food waste is eliminated, then domestic producers will be much more negatively affected than international suppliers. This holds particularly when supply is inelastic, as is generally the case with permanent crops, including many fruits and vegetables.

For the EU as a whole, waste elimination leads, by the mechanisms described above, to a net loss of more than € 400 million annually (Table 13a). The main explanation is that the EU is a net exporter of many commodities. Therefore, much of the benefits of lower prices will accrue to consumers outside the EU. However, EU-consumers also gain substantially while EU-farmers and producers in the processing industries in the EU loose. Finally, the EU "government" loses tariff revenues and quota rents because of the fall in imports caused by the reduction in the households' demand for food and also loses from the increase in supports to agriculture. For the entire world, the net effect is a significant welfare gain, caused by the increased efficiency in consumption implied by waste elimination. Consumers in the least developed countries (LDC) benefit strongly (about € 2 billion annually) from lower food prices, and their gain is not offset by the losses of other agents although profits in most sectors do fall. The same holds true at an even larger scale for the group – Africa (i.e. all African countries) – where agents together reap a benefit of nearly € 4 billion annually. The entire world, including the EU, may gain about € 15 billion annually.

Accordingly, if waste in the EU could be eliminated without costs to consumers, hunger problems would be reduced.

Table 13a: Welfare changes against reference for different agents in different regions of the world when food waste is eliminated (million € annually).

	EU-27	Africa	Sweden	LDC	World
Consumer welfare (equivalent variation)	61 992	6 034	1 004	1 944	104 724
Agricultural profits (including domestic supports)	-57 066	-311	-537	-230	-59 182
Profit of non-agricultural land use	1 506	-1 581	0	-712	-8 445
Profit in feed industry	0	-372	0	-79	-9 107
Profits in processing industry	-257	0	1	4	-1 665
Profits in dairy industry	-3 854	-190	-79	-184	-8 641
Tariff revenues	-2 324	230	-41	76	-1 645
Domestic support outlays	-210	0	-12	0	-198
Tariff rate quota rents	-208	-47	-3	-1	-505
Total	**-420**	**3762**	**332**	**818**	**15 336**

The effects of imposing the tax on consumption of animal products in the EU are presented in table 13b. As expected, these are substantially smaller than if food waste was eliminated without costs. They are, of course, also qualitatively different. For all agents in the EU, the tax leads to a welfare loss of close to a billion euro annually. However, net importing countries such as Sweden may see a small welfare gain. Interestingly, the tax seems to lead to a welfare gain for the world as a whole, which conflicts with received neoclassic theory upon which the model is based. A possible explanation is the existence of subsidies to European agriculture, the negative impacts of which is being offset by the tax. Also consumers of the LDC and Africa gain from the tax via the lower world food prices though, again, profits in most sectors fall.

Table 13b: Welfare changes against reference for different agents in different regions of the world resulting from the tax on animal products (million € annually).

	EU-27	Africa	Sweden	LDC	World
Consumer welfare (equivalent variation)	-18 416	790	-418	224	-15 628
Agricultural profits (including domestic supports)	-4 674	-11	-66	-7	-4 025
Profit of non-agricultural land use	69	-342	0	-109	-874
Profit in feed industry	0	-34	0	-8	-509
Profits in processing industry	-170	-3	-1	0	-429
Profits in dairy industry	-620	-96	-11	-44	-1 193
Tariff revenues	-21	34	0	14	88
Domestic support outlays including revenues from the tax	22 893	0	523	0	22 894
Tariff rate quota rents	-48	-1	-1	0	-102
Total	**-987**	**337**	**27**	**71**	**223**

Thus, while reducing waste in the EU by means of a tax on animal products would reduce hunger problems in poorer countries, the net welfare loss in the EU is larger than the net welfare gains In Africa and the LDC's.

5. Discussion of policy options

The simulation results for the scenario with complete elimination of food waste, without any costs, for EU households reduce emissions of GHG-gasses are reduced by more than 16 million tonnes CO_2 eqv. annually in the EU-27, and by almost 50 million tonnes CO_2 eqv. annually in the world (Table 11). Still, this is only about 0.3 percent of total annual OECD emissions. The effect on nitrate surpluses in EU-27 (which are reduced by 365 000 tonnes annually, Table 12, or by about 3 percent) are also limited. Consumer welfare, however, increases everywhere and, though agricultural profits fall everywhere, and profits in the feed sector as well as in the food processing sector tend to fall in most regions, the net result is a welfare increase in most parts of the world. The exception is the EU-27, where the fall in profits and tariff revenues outweighs the increase in consumer welfare (Table 13a). These results are caused by the assumed increase in consumption efficiency in the EU-27, which reduces purchases of all foods (Table 8b) and, thereby the prices of all foods (Table 9). Accordingly, it would seem as if a complete elimination of food waste at the household level in the EU-27 would have at least some beneficial effects on food security.

However, that scenario is also totally unrealistic as it hinges on the assumption that the increase in consumption efficiency could be achieved without any costs. This is not a viable assumption as reductions in food waste require the households to engage in more careful planning of meal production. This is time-consuming and, hence, entails welfare losses (costs) to the households since time is a scarce resource. It is, therefore, unlikely that households will engage in them unless they are somehow induced to do so.

Because food waste is such a sensitive issue, many suggestions on how to do this have been proposed. Several of the proposals invoke suggestions that are mostly beyond the domain of public policy interventions. The options that will be analysed are listed below. Those are:

- Higher food prices (higher WAT on food)
- Higher fees for garbage collection
- Food waste campaigns/information/education
- Revision/changes in food labeling

Higher VAT on food

Low food prices (in relation to time costs) is the primary cause of food waste in the EU. As The Economist puts it "food is cheap enough for consumers not to worry about chucking it out" (February 24th 2011). Raising food prices would certainly reduce the amount of food waste according to the predictions of the household model and the results of the simulations with the GHG tax on animal products in the CAPRI model.

As in several other EU countries, the VAT on food in Sweden is lower than on other consumer goods (with few exceptions). Rising the VAT on food to the same level as on other goods would increase food prices by approximately 12 percent, assuming that the VAT increase is fully passed on to consumers. Higher prices on all food items result in a non-negligible income effect as well as in an aggregate price (substitution) effect. Both should reduce the amount of food waste.

The CO_2-tax of € 1per kg applied to beef in the EU-27 in the Tax scenario is about 12 percent of the consumer price of beef in the reference scenario. Using the price and income elasticities contained in the CAPRI model, the simulation results show consumer prices increasing by only 9.6 percent (Table 9). Still, the demand for beef in the EU-27 falls by 3 percent, or by about 229 000 tonnes (Table 8b), implying a reduction in GHG emissions caused by the production of beef by about 2.3 – 3.4 million tonnes given that each kg beef emits 10 – 15 kg CO_2 equivalents. As it is assumed that the share of waste rates remain constant (at about 14 percent of the amounts purchased, cf. Table 5), *waste* is only reduced by 32 000 tonnes and GHG emissions from waste by only 320 000 – 480 000 tonnes CO_2-equivalents. However, as demand for other animal products also fall, the net result is that GHG-emissions fall by almost 3 million tonnes CO_2-eqv.

annually in the EU-27, and by almost 8 million tonnes CO_2-eqv annually in the world as a whole (Table 11). For similar reasons, nitrate surpluses fall by about 46 000 tonnes annually in the EU-27 (Table 12).

Regarding welfare effects, Table 13b reveals that consumer welfare in the EU-27, in Sweden, as well as in the whole world, falls. This is also the case for agricultural profits and profits in the processing industry (including dairies) in all regions. In the EU-27, the net result is reduction in aggregate welfare in the EU-27, but not in Sweden, the world as a whole, or in LDC (including Africa). As the LDCs are net importers of animal products, the positive effects on total welfare arise because the tax reduces demand for meat in the EU-27 which, in turn reduces world market prices. For Sweden, the positive effect on total welfare may arise from the fact that the tax reduces domestic production of animal products, which is highly subsidised. Nevertheless, consumer welfare in Sweden is reduced.

However, the assumption of constant waste rates is at odds with the predictions from the household model which suggests that the increase in food prices caused by the tax will induce households to substitute time for food in the production of meals, thereby reducing waste rates. The simulation results, therefore, probably underestimates the tax's effect on waste and, thereby, overestimates the negative effect on consumer welfare in the EU-27 and Sweden.

It may also be noted that an *equi-proportionate* increase in all food prices implies that the *relative* price of some foods will fall and consumers are likely to substitute relatively cheaper (and possibly more perishable) food for more expensive ones. Hence, while food waste would decrease in value terms it may not necessary do so in weight terms if the relatively cheaper food is more perishable. Accordingly, the total effect on food waste in kilograms may depend on the price elasticities of different types of food. As previously pointed out, there is no information about the price elasticity of *waste*, in Sweden or elsewhere, and there are no data available which could allow an estimation of the Becker household model. Accordingly, it is impossible to assess the effects on waste. Probably, a much higher price increase would be needed to substantially reduce waste. A substantial increase in food prices may have adverse distributional effects as poorer households spend a larger share of their income on food. Moreover, households who are more income-constrained than time-constrained, such as unemployed and retired persons, who presumably waste less food, would be unfairly penalised.

In addition, given that it is the negative environmental effects from food production and the disposal of food waste that is the problem, and that the magnitudes of these effects differ between types of food, an equi-proportional increase in all food prices is not an efficient solution. Instead, food prices should be raised according to how much different food types contribute to the environmental costs (as exemplified in the Tax scenario).This would also give households that are more income than time constrained the opportunity to partly avoid the costs of higher food prices by changing to food types that cause less environmental damage.

However, such a solution requires detailed information on the environmental costs of different types of food. These depend on the amount of GHG emissions and nutrient and pesticide leakages that they cause which, in turn, depend on type of soil, production methods, and animal specie (for GHG emissions), and soil type, precipitation, and run other off conditions (for nutrients and pesticides). As soil type, production method, and run off conditions may vary between regions for production of the same type of food, it is not an easy task to construct consumption taxes that properly reflect such differences. Even in the case of animal products, where emissions per kg may be less difficult to estimate, there is the problem of how to allocate the tax between different products obtained from a given animal species. As an example, consider emissions generated by cattle from which one may obtain sirloin steak, entrecote, roast beef, prime rib, minced meat, liver and kidneys. Since these products differ in market prices (per kg), as well as in price- and income elasticities, a given tax in € per kg will have different effects on the demand for each product which may lead to unintended disturbances.

Higher fees for garbage collection

Waste prevention as defined by OECD encompasses strict avoidance, source reduction, product re-use, as well as reducing hazardousness of waste. From the studies above, it is difficult to decide to what extent less food has been wasted at the source and to what extent less food waste has been collected due to composting of waste. From the point of view of handling the waste, the difference may seem unimportant. If, however, the ambition is to reduce the environmental impact of agricultural production, composting the waste and still buying the same quantities is not encouraging.

As an example, Bjuv municipality in Sweden has changed its waste collection system from a fixed collection fee system to one based on a flat fee as well as variable elements based upon the weight of residual and compostable waste. The rate per kilo of residual waste was three times as high as for compostable waste. Initially, the amount of waste dropped considerably. However, the change implied that the cost for waste collection almost doubled. In addition, the subsequent development in Bjuv municipality was not equally encouraging as the quantity of waste started to increase again (Avfall Sverige, 2009). A few years later (2007), the municipality went back to the volume based system. Other Swedish municipalities using weight-based systems are, however, pleased with it (Avfall Sverige, 2009). Approximately 9 percent of the Swedish population is covered by such a system. The experiences of Swedish municipalities indicate that weight-based systems reduce the quantity of waste quantity but that they are more costly to administrate. However, weight-based systems are perceived as fair by the households.

High fees for waste collection may, however, increase incentives for disobedience for some households, resulting in waste being burned in private gardens, dumped illegally or improperly disposed of in other ways. Also, for the fee to provide real incentives to reduce waste, it is crucial that it targets the individual household. Accordingly, higher fees on waste collection are unlikely to be an efficient instrument for households living in apartment blocks where it may not be feasible to ascertain how much food a given household throws away.

Waste awareness campaigns/information/education

As noted in Table 3 (and Appendix 1), information on the problems caused by food waste will only affect behavior if it reveals that food waste causes costs to the individual that was previously un-known. Negative environmental effects are effects that the individual shares with others. Hence, as only parts of the cost fall on the single person, they may only provide limited incentives for actions to reduce them. Moreover, preventive actions by the individual will not reduce the costs caused by other persons. Finally, in the case of GHG emissions, the negative environmental effects will primarily occur in the future. Accordingly, whether or not the individual will act upon new information also depends on her time horizon and rate of discount.

A review of evidence of household waste prevention, by Cox et al (2007) may, perhaps, be suggestive: principal evidence gaps relate to robust and comprehensive quantitative data. A central theme of the review was on consumer behavior change. “It was possible to identify a small number of interventions where waste impacts have been measured, though data limitations were identified that make it difficult to produce a robust overall estimate.” Drawing on the data, our best judgment is that campaigns which target a mix of behaviors can achieve a waste reduction of around 0.5 to 1 kg per household and week. Of separate measures, the highest impacts are observed from home composting.

The potential for food waste reduction campaigns to succeed depends on the attitude of the consumers towards throwing food away. According to an investigation of 1862 British households by Cox and Downing (2007), more than half of the respondents were either not receptive or only “a bit bothered” (26 percent) or not concerned or even resistant to efforts to reduce food waste (33 percent). In contrast, according to Australian study (Baker et al, 2009 op cit), most surveyed households were either “very” or “somewhat” concerned about food waste and 84 percent of them reported feeling guilty about throwing food away.

Swedish consumers are perceived as concerned about global warming and negative effects to the environment. This might make them susceptible to awareness campaigns. However, Swedish experience suggests that financial incentives are important if one wishes to achieve behavioral changes. One example is that sales of new cars using different types of fuels have reacted dramatically to changes in CO_2-taxes and environmental tax-premiums during the period 2006 – 2012 (cf. Statistics Sweden, 2013, for sales statistics; SPBI, 2013, for changes in CO_2-taxes; and Skatteverket 2013 and Transportstyrelsen 2013 for changes in environmental tax-premiums). Accordingly, there are reasons to suspect that effects of awareness campaigns may be quite modest and of limited duration if not backed by financial incentives.

Revision/changes in food labeling

By EU law virtually all food and drink products must bear either “use by” of “best before” labels. Best before is an indication of quality, a date after which food might start to lose its flavour or texture. Many argue that the current labelling approach is too prescriptive and fails to take into account different storage conditions in people homes. It also, arguably, detracts from people making better use of innate senses such as their sight, smell and taste.

The Food Standards Agency (FSA), in the UK analyses annually consumer attitudes to food standards. The results of those surveys vary somewhat over the years but indicate that some consumers are confused about food safety labels. However, some consumers misunderstand the labels in “the opposite” direction believing that food is at its best quality before “use by day” but not necessary unsafe past this date. Confusion of this kind is likely to reduce rather than increase food waste, however, at a health risk.

According to the “Food and You” survey by FSA, 2011: “When it comes to how consumers determine whether food is safe to eat, 72 percent deem food safe by smell, and 56 percent use looks. The recommended practice of checking the ‘use by’ date was mentioned by 25 percent“. These results do not support the hypothesis that label confusion is an important reason for food waste.

On the other hand, in a study by Exodus reported by WRAP (2009), 6 out of 10 respondents claimed that their main reason for throwing away uneaten food was that the food has passed best before or use by date even if it looked edible.

Summary and conclusions

Discussion of the policy options above indicates that a reduction of food waste is quite complicated to achieve. In addition, it may also be pointed out that some actions aiming at reducing food waste may conflict with other societal objectives such a protection of the environment or promotion of healthy diet. For instance, besides more careful planning, food waste reduction may require more frequent shopping and buying smaller packets/containers, which both have negative impact on the environment due to more travel and a higher overall use of packaging materials.

Fruit and vegetables account for large share of total food waste (42.2 percent of the weight according to WRAP) and the share of unavoidable waste for both categories is quite high (around 50 percent or more). Accordingly, a sizeable reduction of total food waste may be difficult to achieve unless consumption of both fruit and vegetable is reduced. However, the present level of consumption of both commodities per capita is substantially below health recommendations.

Of the options discussed above, an increase in the VAT of food would be expected to have the largest effects on food waste. Ideally, the VAT should be raised in accordance with the magnitude of the negative environmental effect (GHG-emissions and nitrogen-leakages) caused by the production of different foods. However, this is not possible as there, presently, is not enough information to quantify these effects. It would also make the intervention administratively demanding and, hence, costly. An equi-proportionate increase in the VAT of all foods could, on the other hand, have detrimental effects on the diets of less affluent households. Such effects could be reduced by only raising the VAT on meat products, but waste of meat products is already comparatively low.

One might consider combining an increase in VAT with awareness campaigns and changes in labeling practices (for instance, only keeping the "use before" date information). However, awareness campaigns are not without costs themselves and the marginal effect of their application would probably be limited since acting on the information and following advices in these campaigns still would impose costs on the households (as a change in the households time-allocation would be required). The effect of changes in labeling practices would probably also be limited since, if we are to believe the results in previous studies, most households do not base decisions upon the label-information only. This suggests that VAT increases still would have to be considerable to achieve a significant reduction in food waste.

Regarding the questions posed at the outset – i.e. whether a reduction in food waste would be an efficient way to reduce agricultures negative impact on the environment, and whether a reduction in food waste would be an efficient way to increase food security – the simulation results show that it the effects on emissions, even if waste could be magically eliminated, are modest indeed. As to the effects on food security, it all depends on how the waste reduction is brought about. Given that economic incentives (higher food prices) are required to induce households to reduce waste, household welfare will be reduced. Provided that those higher food prices only apply to households in wealthier countries, household welfare in LDCs might actually increase through the fall in world market prices brought about by reduced consumption in, say the EU-27. On the other hand, food security is also dependent on producer incentives, and a reduction in demand caused by increasing the VAT on food will affect producer incentives negatively (i.e. world food production will decrease). Hence, though lower world market prices suggest that there will be more food available to "feed the poor" as a result of reduced demand in wealthier countries, there is still the issue of getting this food to where it is needed.

Finally, needless to say, all of the policy options discussed would have to be implemented at an international level (at least the EU-level) in order to affect waste substantially (and particularly if the objective of waste reduction is to reduce emissions of GHG-gasses). If implemented by only one country, they would primarily reduce the competitiveness of that country's producers.

Appendix 1 – the Becker household model

Households are assumed to derive utility (U) from consumption of commodities (Z_i) produced by combining market goods (X_i) with own time (T_i):

$$U = U(Z_1,,,, Z_m) \quad (1)$$

$$Z_i = Z_i(X_i, T_i) \quad (2)$$

Utility is assumed to be a continuous function of the amount of commodities produced with the following properties:

$$\frac{dU}{dZ_i} > 0, \qquad \frac{d^2U}{dZ_i^2} < 0, \qquad \text{and} \qquad \frac{d^2U}{dZ_i dZ_j} > 0 \quad (3a)$$

Goods and time are assumed to be substitutes in the production of Z_i, and the Z_i's are assumed to be continuous functions of X_i and T_i where:

$$\frac{dZ_i}{dX_i} > 0, \quad \frac{d^2Z_i}{dX_i^2} < 0 \qquad \frac{dZ_i}{dT_i} > 0, \quad \frac{d^2Z_i}{dT_i^2} < 0 \qquad \text{and} \qquad \frac{d^2Z_i}{dX_i dT_i} > 0 \quad (3b)$$

The household's budget and time restrictions are, respectively:

$$\sum_{i=1}^{m} P_i X_i = Y + \omega T_\omega \quad (4)$$

$$T_T = \sum_{i=1}^{m} T_i + T_\omega \quad (5)$$

where P_i is the price of good i, Y is non-labour income, ω is the market wage, T_ω is the number of hours worked in the labour market, T_T is total time resources (24 hours) and T_i is time used for the production of commodity Z_i.

As the budget restriction in (4) is not independent of the time restriction in (5), the household in reality only faces one restriction:

$$T_\omega = T_T - \sum_{i=1}^{m} T_i \Rightarrow \sum_{i=1}^{m} P_i X_i = Y + \omega\left(T_T - \sum_{i=1}^{m} T_i\right) \Rightarrow \sum_{i=1}^{m} P_i X_i + \omega \sum_{i=1}^{m} T_i = Y + \omega T_T \quad (6)$$

That is, total expenditures for inputs to produce commodities cannot exceed the income that the household theoretically could obtain (i.e. if all available time were used for market work).

Let: $T_i = t_i Z_i$, where t_i is the number of hours used per unit of Z_i produced
$X_i = x_i Z_i$, where x_i is the number of market goods used per unit of Z_i produced

Then (6) becomes:

$$\sum_{i=1}^{m} P_i x_i Z_i + \omega \sum_{i=1}^{m} t_i Z_i = Y + \omega T_T \Rightarrow \sum_{i=1}^{m} \left(P_i x_i + \omega t_i\right) Z_i = Y + \omega T_T \qquad (7)$$

This gives the Lagrange function:

$$L = U\left[\sum_{i=1}^{m} Z_i(X_i, T_i)\right] + \lambda\left[(Y + \omega T_T) - \sum_{i=1}^{m} (P_i x_i + \omega t_i) Z_i\right] \qquad (8)$$

Maximising (8) with respect to the Z_i's gives the following first order condition:

$$\frac{dL}{dZ_i} = \frac{dU}{dZ_i} - \lambda(P_i x_i + \omega t_i) = 0 \Rightarrow \frac{dU}{dZ_i} = \lambda(P_i x_i + \omega t_i) \qquad (9)$$

That is, the marginal utility of each commodity should equal its marginal costs, which consists of the costs of the goods and the time required to produce a marginal unit of the commodity in question.

This, in turn, implies that:

$$\frac{dU}{dZ_i} / \frac{dU}{dZ_j} = \frac{P_i x_i + \omega t_i}{P_j x_j + \omega t_j} \quad \text{for all commodities } i,j \qquad (10)$$

As cost minimisation is a necessary condition for utility maximisation, x_i and t_i in (10) are the quantities of goods and time that *minimise* the costs of producing a marginal unit of Z_i. These are obtained by solving the problem:

$$\text{Min } C = \sum_{i=1}^{m} (P_i X_i + \omega T_i) + \mu\left\{U^* - U\left[\sum_{i=1}^{m} Z_i(X_i, T_i\right]\right\} \qquad (11)$$

where U^* is some given level of utility.

Accordingly, x_i and t_i are the quantities of X_i and T_i that satisfy:

$$P_i / \frac{dZ_i}{dX_i} = \omega / \frac{dZ_i}{dT_i} = P_j / \frac{dZ_j}{dX_j} = \omega / \frac{dZ_j}{dT_j} \qquad (12)$$

That is, for all commodities *i* and *j*, the cost per unit of *Z* produced by using a marginal unit of *X* should equal the cost per unit produced by using a marginal unit of *T*. I.e. inputs should be combined so that the marginal cost of producing the commodity is the same regardless of what input that is used.

Assume that Z_m is "meals" which are produced by combining "food" (X_m) with time for planning meals, purchasing food, preparing meals, and for preserving left-overs for other use (T_m).

Waste (W) occurs because parts of X_m are inedible ("unavoidable" waste) or because X_m is perishable (avoidable waste). Thus, W is an increasing function of X_m and constitutes a cost since it has been paid for by the household. It may be reduced by using more time for planning and preparation. However, this also entails a cost (i.e. ω per unit of T_m used). It is further assumed that W increases at an increasing rate with the amount of X_m used, but decreases at a decreasing rate with the amount of T_m used. The production function for meals then becomes:

$$Z_m = Z_m\left[X_m, T_m, W(X_m, T_m)\right] \tag{13a}$$

where:

$$\frac{dZ_m}{dX_m} = \frac{\partial Z_m}{\partial X_m} + \frac{\partial Z_m}{\partial W}\frac{\partial W}{\partial X_m} \quad \text{and} \quad \frac{\partial Z_m}{\partial X_m} > 0,\ \frac{\partial Z_m}{\partial W} < 0,\ \frac{\partial W}{\partial X_m} > 0,\ \frac{\partial^2 W}{\partial X_m^2} > 0$$

$$\frac{dZ_m}{dT_m} = \frac{\partial Z_m}{\partial T_m} + \frac{\partial Z_m}{\partial W}\frac{\partial W}{\partial T_m} \qquad \frac{\partial Z_m}{\partial T_m} > 0,\ \frac{\partial Z_m}{\partial W} < 0,\ \frac{\partial W}{\partial T_m} < 0,\ \frac{\partial^2 W}{\partial T_m^2} > 0 \tag{13b}$$

The condition for cost-minimisation corresponding to (12) is therefore:

$$P_m \Bigg/ \left(\frac{\partial Z_m}{\partial X_m} + \frac{\partial Z_m}{\partial W}\frac{\partial W}{\partial X_m}\right) = \omega \Bigg/ \left(\frac{\partial Z_m}{\partial T_m} + \frac{\partial Z_m}{\partial W}\frac{\partial W}{\partial T_m}\right) = P_j \Big/ \frac{dZ_j}{dX_j} = \omega \Big/ \frac{dZ_j}{dT_j} \tag{14}$$

Effects of a change in food prices

Assume first that there is only one type of food and that the cost minimising combination of X_m and T_m has been chosen. An increase in P_m then increases the cost per unit of meal produced by a marginal unit of food. Thus, at the initial combination of X_m and T_m:

$$P_m \Bigg/ \left(\frac{\partial Z_m}{\partial X_m} + \frac{\partial Z_m}{\partial W}\frac{\partial W}{\partial X_m}\right) > \omega \Bigg/ \left(\frac{\partial Z_m}{\partial T_m} + \frac{\partial Z_m}{\partial W}\frac{\partial W}{\partial T_m}\right) \tag{15}$$

inducing the household to use less X_m and more T_m. In addition to this *substitution effect*, the increase in P_m also results in an *income effect* as it tightens the budget constraint in (7). This reduces the household's demand for all Z_i. Thus, the income effect reduces the use of X_m even more but also that of T_m. But, as food expenses only constitute a minor part of the budget, the substitution effect will dominate. Accordingly, X_m declines more than T_m and W will be reduced.

However, a meal may be produced by combining different types of food with time. The condition for cost minimisation corresponding to (14) would be:

$$P_{m1} \Bigg/ \left(\frac{\partial Z_m}{\partial X_{m1}} + \frac{\partial Z_m}{\partial W_{m1}}\frac{\partial W_{m1}}{\partial X_{m1}}\right) = P_{mj} \Big/ \frac{\partial Z_m}{\partial X_{mj}} + \frac{\partial Z_m}{\partial W_{mj}}\frac{\partial W_{mj}}{\partial X_{mj}} = \omega \Bigg/ \left(\frac{\partial Z_m}{\partial T_m} + \frac{\partial Z_m}{\partial W}\frac{\partial W}{\partial T_m}\right) \tag{16}$$

for all types of food $j = 1 \ldots. n$

Suppose that only one of these food prices, say P_{m1}, were to increase. Then $P_{m1}/(dZ_m/dX_{m1}) > \omega/(dZ_m/dT_m) = P_{mj}/(dZ_m/dX_{mj})$. The household adjusts by reducing use of X_{m1} and increasing use of other foods (ΣX_{mj}) and T_m. This substitution effect will reduce W_{m1} (waste of X_{m1}) but increase ΣW_{mj} if the increase in T_m does not eliminate waste from the additional use of X_{mj}. The income effect caused by the increase in P_{m1} will reduce the use of all types of food, as well as of time. This would further reduce use of X_{m1} and counteract the increase in use of both X_{mj} and T_m. However, as food expenses only constitute a small share of the household's budget, the substitution effect will dominate. Hence, the effect on total waste ($W_{m1} + \Sigma W_{mj}$) is indeterminate.

Effects of a fee on waste

Higher food prices may be regarded undesirable as it is W, not X_m per se, that is the problem. Consider levying a fee on waste (F_w) instead. This changes the budget restriction in (6) to:

$$\sum_{i=1}^{m} \left[P_i x_i + F_w W(x_m, t_m) + \omega t_i \right] Z_i = Y + \omega T_T \tag{17}$$

and the condition for cost-minimisation to:

$$\frac{P_m + F_w \dfrac{\partial W}{\partial X_m}}{\dfrac{\partial Z_m}{\partial X_m} + \dfrac{\partial Z_m}{\partial W}\dfrac{\partial W}{\partial X_m}} = \frac{\omega + F_w \dfrac{\partial W}{\partial T_m}}{\dfrac{\partial Z_m}{\partial T_m} + \dfrac{\partial Z_m}{\partial W}\dfrac{\partial W}{\partial T_m}} = P_j \Big/ \frac{dZ_j}{dX_j} = \omega \Big/ \frac{dZ_j}{dT_j} \tag{18}$$

As $\left(\partial W / \partial X_m\right) > 0$, the numerator of the first term in (18) is *larger* than the numerator of the first term in (14), implying that F_w raises the cost per unit of Z_m produced by using X_m. Similarly, as $\left(\partial W / \partial T_m\right) < 0$, the numerator of the second term in (18) is *smaller* than that of the second term in (14), implying that F_w reduces the cost per unit of Z_m produced by using T_m. Thus, the cost-minimising combination of inputs should contain less X_m and more T_m. At first, it seems that F_w reduces W in the same way as an increase in P_m. However, for households to take account of F_w when choosing the cost-minimising combination of inputs requires that W can be verified at household level which may be administratively demanding and, hence, unfeasible.

Effects of an increase in wages

The effects of an increase in the wage rate (ω) may be of interest as the marginal productivity of time in the labour market is expected to increase due to technological progress. This would raise the cost per unit of meal produced by use of time. Thus, at the initial combination of X_m and T_m:

$$P_m \Big/ \left(\frac{\partial Z_m}{\partial X_m} + \frac{\partial Z_m}{\partial W}\frac{\partial W}{\partial X_m} \right) < \omega \Big/ \left(\frac{\partial Z_m}{\partial T_m} + \frac{\partial Z_m}{\partial W}\frac{\partial W}{\partial T_m} \right) \tag{19}$$

The substitution effect caused by the increase in ω induces the household to reduce use of T_m and increase use of X_m. This will increase W. An increase in ω also increases ωT_T. This income effect will increase the use of X_m even further but also the use of T_m. Given that the cost of time used for meal production is a relatively small part of the budget, the substitution effect will dominate. Accordingly, more X_m and less T_m will be used in meal production and W increases.

Effects of a change in non-labour income

An increase in non-labour income (Y) results in an income effect only. This increases demand for all Z_i, inducing the household to purchase more X_i and T_i, including X_m and T_m for production of Z_m. Other things equal this is likely to increase W. For instance, assume that the production function $Z_m(X_m,T_m)$ is such that the ratio of marginal products $(dZ_m/dX_m)/(dZ_m/dT_m)$, remains constant if use of X_m and T_m were to increase in the same proportion. Given P_m and ω, W per meal would not change. Nevertheless, total W would still increase as the demand for meals, and thereby the use of X_m, increases.

Next, assume Z_m is such that $(dZ_m/dX_m)/(dZ_m/dT_m)$ *increases* if use of X_m and T_m were to increase in the same proportion. At given P_m and ω, the cost-minimising combinations of X_m and T_m would then include relatively more food and less time when the demand for meals increased. This would increase W not only because the demand for meals increases but also because each meal is produced by more food intensive methods.

Finally, assume Z_m is such that $(dZ_m/dX_m)/(dZ_m/dT_m)$ *decreases* if use of each input were to increase in the same proportion. Other things equal, the cost-minimising combinations would include relatively more T_m and less X_m as the demand for meals increased. But, as use of X_m would still increase, W would only be reduced if the increase in T_m eliminated the waste caused by the increase in X_m. Although this cannot be ruled out on theoretical grounds, it is unlikely.

Effects of more knowledge in meal production

Better knowledge (K_m) of Z_m would facilitate planning and preparation of meals, as well as preservation of left overs. This suggests:

$$Z_m = Z_m\left[X_m, T_m, W(X_m, T_m, K_m)\right] \tag{20a}$$

where:

$$\frac{\partial W}{\partial K_m} \leq 0, \qquad \frac{\partial^2 W}{\partial X_m \partial K_m} < 0, \qquad \frac{\partial^2 W}{\partial T_m \partial K_m} < 0 \tag{20b}$$

Thus, an increase in K_m reduces W for any given quantity of Z_m. On the other hand, it also reduces the costs of producing Z_m (as less X_m and T_m would be required for a given quantity of Z_m) in relation to those of other commodities (Z_j). Assume that the increase in K_m does not change the cost-minimising combination of X_m and T_m. However, with respect to Z_j, an increase in K_m implies that at the initial allocation of resources:

$$P_m \Big/ \left(\frac{\partial Z_m}{\partial X_m} + \frac{\partial Z_m}{\partial W}\frac{\partial W}{\partial X_m} \right) = \omega \Big/ \left(\frac{\partial Z_m}{\partial T_m} + \frac{\partial Z_m}{\partial W}\frac{\partial W}{\partial T_m} \right) < P_j \Big/ \frac{dZ_j}{dX_j} = \omega \Big/ \frac{dZ_j}{dT_j} \tag{21}$$

That is, the initial allocation does not minimise the costs of commodity production in general, implying that it does not maximise utility. Hence, the reduction in the costs of Z_m will increase the demand for, and the production of, Z_m. This will counteract the reduction in W caused by better knowledge (given that the latter does not completely eliminate W). However, if the price elasticity of demand for Z_m is less than unity, an increase in K_m would still reduce W.

Effects of information on problems caused by food waste

Food waste is problematic not only because it increases the costs of meal production but also because food production results in emissions of GHGs and nutrients. Now, suppose households were unaware of the full negative consequences of their food waste, would additional information increase their efforts to reduce it?

This would be the case only if the information reveals that waste causes some previously unknown private cost or disutility for the household. If it is a cost, the effects of the information received would be similar, in model terms, to those of a fee on waste discussed above. If it is a disutility, the effect would go through the utility function. It might be argued that the latter would be the case if people were concerned about the utility of others and accepted the argument that waste is unethical. In that case, the cost-minimisation problem becomes:

$$\text{Min } C = \sum_{i=1}^{m} (P_i X_{Hi} + \omega T_{Hi}) + \\ + \mu \left\{ U_H^* - U_H \left(\sum_{i=1}^{m} Z_{Hi} \left[X_{Hi}, T_{Hi}, W_H(X_{Hm}, T_{Hm}) \right], U_O \left[W_H(X_{Hm}, T_{Hm}) \right] \right) \right\} \quad (22)$$

where U_H is household H's utility, which is a function of own production and consumption of commodities (Z_{H1}, , , , Z_{Hm}, where Z_{Hm} is a negative function of own waste, W_H), and of the utility of other households (U_O, where $dU_H/dU_O > 0$) which, in turn, is a negative function of household H's waste ($dU_O/dW_H < 0$).

Hence, instead of (14) above, the condition for cost-minimisation becomes:

$$P_m / \left[\frac{\partial U_H}{\partial Z_{Hm}} \left(\frac{\partial Z_{Hm}}{\partial X_{Hm}} + \frac{\partial Z_{Hm}}{\partial W_H} \frac{\partial W_H}{\partial X_{Hm}} \right) + \frac{dU_H}{dU_O} \frac{dU_O}{dW_H} \frac{dW_H}{dX_{Hi}} \right] =$$

$$\omega / \left[\frac{\partial U_H}{\partial Z_{Hm}} \left(\frac{\partial Z_{Hm}}{\partial T_{Hm}} + \frac{\partial Z_{Hm}}{\partial W_H} \frac{\partial W_H}{\partial T_{Hm}} \right) + \frac{dU_H}{dU_O} \frac{dU_O}{dW_H} \frac{dW_H}{dT_{Hm}} \right] = \quad (23)$$

$$P_j / \frac{dU_H}{dZ_{Hj}} \frac{dZ_{Hj}}{dX_{Hj}} = \omega / \frac{dU_H}{dZ_{Hj}} \frac{dZ_{Hj}}{dT_{Hj}}$$

Now, since:

$$\frac{dU_O}{dX_{Hm}} = \frac{dU_O}{dW_H} \frac{dW_{HI}}{dX_{Hm}} < 0 \quad \text{and} \quad \frac{dU_O}{dT_{Hm}} = \frac{dU_O}{dW_H} \frac{dW_H}{dT_{Hm}} > 0 \quad (24)$$

the first term (first row) in (23) is larger than the first term in (14), while the second term (second row) in (23) is smaller than the second term in (14). Accordingly, the information that waste may deprive poor people of food increases the household's costs per unit of Z_m produced by a marginal unit of food and reduces the household's cost per unit of Z_m produced by a marginal unit of time. The new cost-minimising combination of food and time in meals production will, therefore, contain less X_m and more T_m which will reduce W.

Appendix 2 – modeling the demand chock in the CAPRI model

This note develops a microeconomic model of consumption, based on an indirect utility function with a semi-flexible functional form, where food waste is a fix proportion of food purchases and where waste is considered a worthless by-product with no other uses. The aim is to analyse the impact of a reduction of the rate of food waste on food demand by households.

Shocking a demand system based on indirect utility

There are many ways to skin a cat, and also to derive a demand system. Since the intention is to use the results of the derivations to shock the CAPRI model, we chose the same approach as that of CAPRI, by assuming an indirect utility function of the Generalized Leontief type.

Let there be n goods (some of which some are foods), and denote demand for the i[th] good by X_i and its market price by P_i. Some of the quantity bought of each good is wasted in the household during handling, storage, preparation, and left-over from consumption. We assume that the household draws no utility whatsoever from waste, and that waste is a worthless by-product. The quantity of food that is actually consumed is denoted by the Greek letter "xi", ξ_i, and it is assumed to be a fixed share α_i of total purchases by the household. We can thus write total food actually consumed in the following way:

$$\xi_i(\alpha_i) = \alpha_i X_i$$

In particular, we are interested in simulating the impact of changing the rate of food losses. We therefore assume that the degree of utilization is a function of a reference rate of waste W_i^* and technical shift in consumption r_i that reduces waste so that $\alpha_i(r) = 1 - W_i^* + r_i$. The aim of this section is to derive the impact of reducing waste on total food purchases, i.e., $\partial X_i / \partial r_i$.

The indirect utility function resulting from utility maximization under a budget constraint can be written in the following two fully equivalent ways, depending on whether the quantities *bought* or the quantities actually *consumed* (purchases net of waste) is considered to be the decision variable, if a corresponding scaling of the prices is made:

$$v(P_1,..., P_n, M, \alpha_1,..., \alpha_n) = \left\{ \max U(\alpha_1 X_1,..., \alpha_n X_n) : \sum_{i=1}^{n} P_i X_i - M = 0 \right\}$$

$$v^*\left[\pi_1(P_1, \alpha_1),...., \pi_n(P_n, \alpha_n)\right] = \left\{ \max U(\xi_1,..., \xi_n) : \sum_{i=1}^{n} \pi_i(P_i, \alpha_i)\xi_i - M = 0 \right\} \qquad (1)$$

$$v(P, M, \alpha) \equiv v^*\left[\pi(P, \alpha), M\right]$$

To obtain the equivalence between v and v^* in expression (1), we first substitute $X_i = \xi_i / \alpha_i$ for X_i in the first maximization problem (thereby changing nothing), and then define the price π_i of ξ_i to be $\pi_i(P_i, \alpha_i) = P_i / \alpha_i$. The purpose of setting up the equivalent indirect utility function

v^* is that it funnels the impact through the prices $\pi_i(P_i, \alpha_i)$ instead of via the (unknown) direct utility function, allowing us to find the effect on consumption via Roy's identity.

Using the definitions and terminology described above, we can now differentiate demand X_i with respect to the technical shift in consumption r_i.

$$\frac{\partial X_i}{\partial r_j} = \frac{\partial X_i}{\partial \alpha_j}\frac{\partial \alpha_j}{\partial r_j} = \frac{\partial[\xi_i(\alpha)/\alpha_i]}{\partial \alpha_j} = \left(\frac{1}{\alpha_i}\frac{\partial \xi_i}{\partial \alpha_j} - I_{i,j}\frac{X_i}{\alpha_j}\right) \tag{2}$$

The first equality follows from the chain rule of differentiation, because X_i is a function of all α, which are in turn a function of r, with $\partial\alpha_i / \partial r_i = 1$. The second equality follows from the definition of losses given above and from that eating (ξ_i) is a function of all α, i.e. $X_i(\alpha) = \xi_i(\alpha) / \alpha_i$. The third equality follows from an application of the product and chain rules for differentiation, and the parameter $I_{i,j}$ indicates whether or not $i = j$, i.e. $I_{i,j} = 1$ if $i = j$ and $I_{i,j} = 0$ if $i \neq j$.

In the last parenthesis of equation (2), we may use the fact that ξ_i is a function of π and expand the partial derivative:

$$\frac{\partial \xi_i}{\partial \alpha_j} = \frac{\partial \xi_i}{\partial \pi_j}\frac{\partial \pi_j}{\partial \alpha_j} = -\frac{\partial \xi_i}{\partial \pi_j}\frac{P_j}{\alpha_j^2},$$

to obtain the following expression:

$$\frac{\partial X_i}{\partial r_j} = -\left(\frac{1}{\alpha_i}\frac{\partial \xi_i}{\partial \pi_j}\frac{P_j}{\alpha_j^2} + I_{i,j}\frac{X_i}{\alpha_j}\right) \tag{3}$$

The key unknown element in expression (3) is the partial derivative $\partial\xi_i / \partial\pi_j$ inside the parenthesis, and we may obtain an expression for that one using the indirect utility functions defined in (**Error! Reference source not found.**). First we apply *Roy's identity* to $v^*[\pi(P, \alpha), M]$:

$$\xi_i[\pi(P,\alpha), M] = \frac{\partial v^* / \partial \pi_i}{\partial v^* / \partial M} \tag{4}$$

This expression can be differentiated once more with respect to prices to obtain the following partial derivatives, to be used in equation (3):

$$\frac{\partial \xi}{\partial \pi_j} = -\left[\frac{\partial^2 v^*}{\partial \pi_i \partial \pi_j}\frac{1}{\partial v^* / \partial M} - \frac{\partial^2 v^*}{\partial M \partial \pi_j}\frac{\partial v^* / \partial \pi_i}{(\partial v^* / \partial M)^2}\right] \tag{5}$$

The final step is now to find a way of expressing the partial derivatives of v^* in terms of the given indirect utility function v. Both sides of the identity on the last row of expression (1) are assumed to be twice differentiable with respect to prices and budget, and since we are dealing with an identity, the resulting partial derivatives will also be identical. Differentiation and rearranging of factors gives the following partial derivatives, to be used later on:

$$\frac{\partial v^*}{\partial \pi_i} \equiv \alpha_i \frac{\partial v}{\partial P_i} \tag{6}$$

$$\frac{\partial^2 v^*}{\partial \pi_i \partial \pi_j} \equiv \alpha_i \alpha_j \frac{\partial^2 v}{\partial P_i \partial P_j} \tag{7}$$

$$\frac{\partial v^*}{\partial M} \equiv \frac{\partial v}{\partial M} \tag{8}$$

$$\frac{\partial^2 v^*}{\partial M \partial \pi_i} \equiv \alpha_i \frac{\partial^2 v}{\partial M \partial P_i} \tag{9}$$

Insertion into (5) and then into (3) and collection of terms yields the following expression:

$$\begin{aligned} \frac{\partial X_i}{\partial r_j} &= \frac{P_j / \alpha_j}{\partial v / \partial M} \left(\frac{\partial^2 v}{\partial P_i \partial P_j} + \frac{\partial^2 v}{\partial M \partial P_j} X_i \right) - I_{i,j} \frac{X_j}{\alpha_j} \Rightarrow \\ \frac{\partial X_i}{\partial r_j} &= \frac{P_j / \alpha_j}{\partial v / \partial M} \frac{\partial^2 v}{\partial P_i \partial P_j} - \frac{P_j / \alpha_j}{\partial v / \partial M} \frac{\partial^2 v}{\partial P_i \partial P_j} \frac{\partial v / \partial P_i}{\partial v / \partial M} + I_{i,j} \frac{\partial v / \partial P_i}{\partial v / \partial M} \end{aligned} \tag{10}$$

In words, this equation (10) shows that demand will shift because of three mechanisms when r increases (waste is reduced), but it will not be possible to tell the direction of change *a-priori*.

1. The last term will *reduce* demand for the good for which losses are reduced, because less food needs to be purchased in order to maintain any level of actual consumption (eating the same quantity).
2. The first term tends to *increase* demand for good i if losses of that good are reduced, because the "price of eating" has been reduced. The consumer no longer has to pay for as much waste associated with consumption. The size of that term (in relation to the last term) depends critically on the second order derivative, which is associated with the matrix of price elasticities.
3. The second term also tends to increase demand for good i, and since it works primarily over the partial derivatives w.r.t. income we call it the income effect.

Implementation of waste shock in a GL demand system

In CAPRI, indirect utility takes the following functional form (Ryan and Wales, 1999):

$$v(P, M) = -\frac{g(P)}{M - f(P)}$$

where: $g(P_1, ..., P_n) = \sum_i \sum_j B_{ij} \sqrt{P_i P_j}$ $\quad f(P_1, ...P_n) = \sum_i d_i P_i$

The partial derivatives of $v(P, M)$ are:

$$\frac{\partial v}{\partial P_i} = \frac{-1}{M - f(P)} \left(\frac{\partial g(P)}{\partial P_i} + \frac{g(P)\left[\partial f(P) / \partial P_i\right]}{M - f(P)} \right)$$

$$\frac{\partial v}{\partial M} = \frac{g(P)}{\left[M - f(P)\right]^2}$$

$$\frac{\partial^2 v}{\partial P_i \partial P_j} = \frac{-1}{M - f(P)} \left(\frac{\partial^2 g(P)}{\partial P_i \partial P_j} + \frac{\frac{\partial g(P)}{\partial P_i}\frac{\partial f(P)}{\partial P_{j)}} + \frac{\partial g(P)}{\partial P_j}\frac{\partial f(P)}{\partial P_i}}{M - f(P)} + \frac{2g(P)\frac{\partial f(P)}{\partial P_i}\frac{\partial f(P)}{\partial P_j}}{\left[M - f(P)\right]^2} \right)$$

$$\frac{\partial^2 v}{\partial M \partial P_i} = \frac{1}{\left[M - f(P)\right]^2} \left(\frac{\partial g(P)}{\partial P_i} + \frac{2g(P)\frac{\partial f(P)}{\partial P_i}}{M - f(P)} \right)$$

where:

$$\frac{\partial g(P)}{\partial P_i} = \frac{1}{\sqrt{P_i}} \frac{\sum_j B_{ij}}{\sqrt{P_j}} \qquad \frac{\partial^2 g(P)}{\partial P_i \partial P_j} = \frac{B_{ij}}{2\sqrt{P_i P_j}} \; \forall j \neq i \qquad \frac{\partial^2 g(P)}{\left(\partial P_i\right)^2} = -\frac{\sum_{i \neq j} B_{ij}\sqrt{P_j}}{\sqrt{P_i}}$$

$$\frac{\partial f(P)}{\partial P_i} = d_i$$

Referring to the three terms of (**Error! Reference source not found.**), using the specific functional form for the indirect utility, we obtain the following price, income and direct effects:

Price effect:

$$\frac{P_j / \alpha_j}{\partial v / \partial M} \frac{\partial^2 v}{\partial P_i \partial P_j} \Delta r_j = -P_j \left(\frac{\frac{\partial g(P)}{\partial P_j}}{g(P)}\left[M - f(P)\right] + \frac{\frac{\partial f(P)}{\partial P_i}\frac{\partial g(P)}{\partial P_j} + \frac{\partial f(P)}{\partial P_j}\frac{\partial g(P)}{\partial P_i}}{g(P)} + \frac{2\frac{\partial f(P)}{\partial P_i}\frac{\partial f(P)}{\partial P_j}}{M - f(P)} \right) \frac{\Delta r_j}{\alpha_i}$$

Income effect:

$$-\frac{P_j / \alpha_j}{\partial v / \partial M} \frac{\partial^2 v}{\partial P_i \partial P_j} \frac{\partial v / \partial P_i}{\partial v / \partial M} \Delta r_j = \frac{P_j}{\alpha_j} \left(\frac{\frac{\partial g(P)}{\partial P_j}}{\alpha_j} + \frac{2\frac{\partial f(P)}{\partial P_j}}{M - f(P)} \right) \left(\frac{\frac{\partial g(P)}{\partial P_i}\left[M - f(P)\right]}{g(P)} + \frac{\partial f(P)}{\partial P_i} \right) \Delta r_j$$

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