Computable General Equilibrium Simulations of the Effects on the U.S. Economy of Reductions in Beef Consumption

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Computable general equilibrium simulations of the effects on the U.S. economy of reductions in beef consumption

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Abstract:

We use USAGE-Food, a modified version of the USAGE model, to simulate the effects on the U.S. economy of reductions in meat consumption brought about by health-related preference changes or induced by taxes. Modifications include: (a) separate identification of Beef processing; (b) estimates of price elasticities of demand for beef and other food products derived from a survey of econometric studies; (c) nesting in the household utility function and in the production functions of food-serving industries to represent substitution between flesh and non-flesh food; and (d) allowance for flows of agricultural land between agricultural activities.

At the macro level, the main influences on our results are health-related effects on medical expenditures and labour supply. The pure food-chain effects have negligible macroeconomic consequences. Other conclusions are:

- using beef-tax revenue to subsidize healthy foods strongly accentuates substitution away from beef towards healthy foods. However, the subsidy leads to an overall increase in the consumption of food.
- using beef-tax revenue to expand public consumption has a negative effect on private consumption. In terms of aggregate demand, the two effects are broadly offsetting.

JEL codes: C68; I19; Q18

Key words: Reducing U.S. beef consumption; CGE simulations; effects via health expenditures; effects via labour supply

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Summary

(1) The CSIRO and Johns Hopkins University are researching the effects of reducing beef consumption in the U.S. To support this work, the Centre of Policy Studies at Victoria University has performed relevant simulations with the USAGE model of the U.S. economy. In August 2019, we submitted a report containing results for 5 preliminary simulations. The August report is included as part 2 of this report. Part 1 contains the final simulations that were completed in December 2019.

(2) USAGE is a dynamic computable general equilibrium (CGE) model identifying 392 industries/commodities. The model has been widely used by and on behalf of agencies of the U.S. government in Washington DC.

(3) For this project, we have modified standard USAGE to create USAGE-Food. The modified model emphasises substitution possibilities between different food products.

(4) In the preliminary report, we used USAGE-Food to create 5 building blocks for the analysis of beef-consumption-reducing policies. These building blocks are simulations that show the effects on macro and industry variables of:

- (a) a reduction in beef consumption brought about by a beef tax;
- (b) a reduction in beef consumption caused by a preference shift against beef towards other food products in general;
- (c) a reduction in beef consumption caused by a preference shift against beef towards a particular set of food products that are the main ingredients in the creation of meat alternatives (veggie burgers, beyond meat, etc);
- (d) a reduction in requirements for health services that we imagine could be associated with a diet-related improvement in the health of the U.S. population; and
- (e) an increase in labor-force participation that we imagine could be associated with a diet-related improvement in the health of the U.S. population.

(5) The project has benefited from considerable interaction between the sponsoring team at Johns Hopkins University and the modelling team at CSIRO and Victoria University. Since the August report, this interaction has led to four sets of improvements in USAGE-Food. These involved:

- (a) The identification in USAGE-Food of Beef processing as a separate commodity/industry. In the August report beef processing was the major part of Animal processing, which also included pork and lamb.
- (b) The conduct by the modeling team of a survey of econometric studies of price elasticities of demand for beef and other food products. Results from this survey have now been incorporated in USAGE-Food.
- (c) The inclusion of extra nesting in the household utility function and in the production functions of food-serving industries such as restaurants, colleges, etc. This extra nesting facilitated the simulation of substitution effects between flesh and non-flesh food.
- (d) Allowance for limited flow of agricultural land between different agricultural activities.

(6) We conducted 11 simulations with the improved version of USAGE-Food. The first 5 are revisions of the 5 building-block simulations supplied in August. The next 6 are new simulations arising from discussions with the Johns Hopkins sponsors.

(7) With beef now more narrowly defined, the revised beef-reduction simulations (N1, N2 and N3) generally show smaller macroeconomic effects than the corresponding earlier simulations (1, 2 and 3).

(8) After a survey of relevant literature, we have sharply scaled down the health-benefit simulation (compare simulation N4 with August simulation 4).

(9) The labor-supply simulation (N5) is barely changed from the August simulation (5).

(10) The health and labor-supply simulations continue to show much larger macro-economic effects than simulations concerned with the direct effects of reduction in beef consumption in favor of other food products.

(11) In conjunction with the revised building-block simulations, the 6 new simulations (labelled N6 to N11) show the effects of:

(N6) using beef-tax revenue to subsidize the consumption of healthy food;

(N7) using beef-tax revenue to expand public expenditure;

(N8) adopting a 30 per cent target for a tax-induced reduction in beef consumption rather than a 10 per cent target;

(N9) a 30 per cent cut in beef consumption (instead of 10 per cent) brought about by a preference shift from beef to meat alternatives;

(N10) a 60 per cent cut in beef consumption (instead of 10 per cent) brought about by a preference shift from beef to meat alternatives;

(N11) a 15 per cent cut in beef consumption brought about by a preference shift to healthy food.

(12) Simulation N6 implies that using beef-tax revenue to subsidize healthy foods can strongly accentuate the substitution effect away from beef towards healthy foods. However, there is a macro economic cost. In addition, the subsidy leads to an overall increase in the consumption of food.

(13) Simulation N7 implies that using beef-tax revenue to expand public consumption has a negative effect on private consumption. In terms of aggregate demand, the two effects are broadly offsetting. The substitution of public demand for private demand has a slightly negative affect on capital and GDP.

(14) Simulation N8 implies that there are sharply increasing macroeconomic costs of using a beef tax to achieve more ambitious beef-consumption-reduction targets.

(15) Simulations N9 and N10 imply that the effects of ambitious beef-consumption-reduction targets achieved through preference changes are equal, to a close approximation, to scaled up effects from less ambitious targets.

(16) Simulation N11 implies that reduction in beef consumption in favor of healthy foods has slightly negative macro-economic effects compared with the situation in which beef is replaced by meat alternatives. These slightly negative effects reflect low capital intensity in the production of healthy foods relative to beef processing and relative to the production of meat alternative.

(17) We illustrate how our results from the 11 simulations can be combined to create approximations to results from other simulations. As an example, we discuss a combination of N6 and N11. This combination produces a 25 per cent reduction in beef consumption brought about by a beef tax and a preference shift together with a strong increase in consumption of healthy foods brought about by subsidization and a preference shift.

CONTENTS

PART 1

N1. Introduction

This report describes USAGE-Food model simulations showing the effects on U.S. industries and the U.S. macro economy of reductions in the consumption of beef. The report has two parts. The second part is a slightly revised version of our preliminary report presented in August 2019. That preliminary report contained 5 simulations with detailed explanations covering all of the economic mechanisms captured in the USAGE-Food model. It also contained copious background material on USAGE. The first part of this report contains results for 11 further simulations. While we produce detailed tables of results for these simulations, we keep the explanations brief.

In running these 11 new simulations, we used a version of USAGE-Food that incorporates four sets of improvements relative to the version used in the August report. These improvements are as follows:

(a) In the August report, the beef commodity sold to consumers was about 2/3rds of a broader commodity category entitled part "Animal processing". The other third is mainly pork and lamb (poultry is a separate commodity produced by a separate industry). For the new simulations in the first part of this report we use a version of USAGE-Food in which both the Animal processing commodity and industry are split into two parts: Beef processing and Other animal processing.

(b) We made a detailed survey of econometric studies of price elasticities of demand for beef and other food products. These studies suggest three things. First, the own-price elasticity of demand for a meat item at a disaggregated level is about -1. This means that if the price of Beef for example rises by 1 per cent holding constant the price of other meat commodities, then the demand for beef falls by about 1 per cent. Second, the own-price elasticity for meat in general is about -0.6. This means that if the price of Beef together with that of all other meat products rises by 1 per cent, then the demand for Beef falls by only about 0.6 per cent. Third, cross-price elasticities are relatively small and can be of either sign. This means that if the price of Poultry rises by 1 per cent holding constant the prices of other meat products, then the demand for Beef may either rise or fall but the effect is likely to be small. As explained in Appendix N1 to the first part of this report, we introduced these stylized econometric findings to USAGE-Food by adopting appropriate parameter values in a 3-level nested utility function describing consumer preferences. The first level includes food as a single commodity together with USAGE-Food's 365 non-food commodities. The second level splits Food into Flesh and Nonflesh. The third level splits Flesh into 6 standard input-output meat commodities and Nonflesh into 21 standard input-output non-meat food commodities.

(c) Similarly, we used a nested production function to describe Food use by food-serving industries (restaurants, colleges, etc). Again, Food was split into Flesh and Nonflesh and then Flesh and Nonflesh were split into 6 meat commodities and 21 non-meat food commodities.

(d) In the August report, USAGE-Food was set up with each agricultural industry having a fixed allocation of land. There was no flow of land between agricultural industries. Thus, in simulations involving a sharp reduction in the output of Cattle ranching, there was a sharp reduction in the rental value of cattle-ranching land. In the improved version of the model, we allow for limited conversion of cattle-ranching land to land for other agricultural purposes. This smooths out the response of land-rental rates to changes in the composition of agricultural output.

The 11 new simulations can be split into two groups. The first group consists of 5 simulations that can be regarded as revised versions of the 5 simulations in our August report. The revisions come mainly from improvements (a) to (d) in the model. The second group of 6 simulations were suggested by our sponsors at Johns Hopkins University.

The setup for the 11 simulations can be summarized as follows.

Revised simulations

Simulation N1. We introduce a consumer tax on beef calibrated to reduce consumption (quantity purchased by households) of beef by 10 per cent. Revenue from the tax is returned to households by a uniform across-the-board percentage-point reduction in consumer taxes on all other commodities.

Simulation N2. We introduce a preference shift by households against beef calibrated to reduce consumption of beef by 10 per cent. Correspondingly there is a uniform percentage-point preference shift towards consumption of all other food commodities. The net preference shift towards food is zero. Table N1.1 indicates the USAGE-Food commodities included in Food.

Simulation N3. We introduce a preference shift by households against beef calibrated to reduce consumption of beef by 10 per cent. Correspondingly there is a uniform percentage-point preference shift towards consumption of products that are the main constituents of meat alternatives such as Beyond meat and Veggie burgers. The net preference shift away from beef and towards these other products is zero. Table N1.1 indicates the commodities making up meat-alternative constituents.

Simulation N4. As explained in our August report, one of the potential benefits of reduced beef consumption is an improvement in the health of U.S. residents. In the August report we illustrated the economic effects of a health improvement by introducing a 3.32 per cent reduction in public and private expenditures on health services. Working with Daniel Mason-D'Croz, we decided for this report that 0.5 per cent is a more realistic magnitude for the percentage cut in health expenditure. Thus, simulation N4 in this new report is a scaled-down version of simulation 4 in the August report, with the health-expenditure cut scaled down from 3.32 per cent to 0.5 per cent. As in the August report, we assume that public saving on health expenditure is returned to households by a general cut in taxes and that private saving on health expenditure is used by households to facilitate across-the-board expansion in consumption of other commodities.

Simulation N5. As explained in our August report, another potential benefits of reduced beef consumption is a health-related increase in labor-force participation, particularly by workers aged between 50 and 70. As in the earlier report, we illustrate the effects of an increase in labor-force participation by a shock to labor supply of 0.39 per cent. The resulting increase in public-sector taxation revenues and reduction in social-security payments is returned to households by a general cut in household taxes.

New simulations

Simulation N6. This is the same as simulation N1 except that the revenue from the beef tax is used to provide a uniform percentage-point subsidy on the consumption of healthy-food commodities. Table N1.1 indicates the commodities that we included in the healthy group.

Table N1.1. Food commodities and food subsets in USAGE-Food

Food commodities	Food commodities mapped into 2 subcategories	Constituents of alternative meat products	Healthy foods
VegMelonFarm	Nonflesh	OilSeedFarm	VegMelonFarm
FruitNutFarm	Nonflesh	GrainFarm	FruitNutFarm
PoultryEgg	Flesh	OthCropFarm	FlourMillMalt
FishHuntTrap	Flesh	FlourMalMill	WetCornMill[2]
FlourMillMalt	Nonflesh	WetCornMill	SoyOilseedProc
WetCornMill	Nonfleah	SoyOilProc	FatsOils
SoyOilseedProc	Nonflesh	FatsOils	FrtVegCanning
FatsOils	Nonflesh		
BreakCereal	Nonflesh		
SugarConfec	Nonflesh		
FrozFood	Nonflesh		
FrtVegCanning	Nonflesh		
MilkButter	Nonflesh		
Cheese	Nonflesh		
DryCondEvapDairy	Nonflesh		
IceCream	Nonflesh		
BeefProc	Flesh		
OthAnimProc	Flesh		
PoultryProc	Flesh		
Seafood	Flesh		
BreadBakery	Nonflesh		
CookiePasta	Nonflesh		
SnackFood	Nonflesh		
CoffTea	Nonflesh		
FlavorSyrup	Nonflesh		
SeasDressing	Nonflesh		
OthrFoodManu	Nonflesh		

Simulation N7. This is the same as simulation N1 except that the revenue from the beef tax is used to increase public expenditure by a uniform percentage across all commodities purchased by federal, state and local governments.

Simulation N8. This is the same as simulation N1 except that the beef tax is calibrated to reduce beef consumption by 30 per cent instead of 10 per cent. As in simulation N1, revenue from the beef tax is returned to households by a uniform percentage reduction in taxes on all other commodities.

Simulation N9. This is the same as simulation N3 except that the preference shift against beef towards meat-alternative commodities is calibrated to reduce beef consumption by 30 per cent instead of 10 per cent. (Table N1.1 indicates the commodities making up meat-alternative constituents.)

Simulation N10. This is the same as simulations N3 and N9 except that the preference shift against beef towards meat-alternative commodities is calibrated to reduce beef consumption by 60 per cent.

Simulation N11. In this simulation there is a 15 per cent reduction in consumption of beef induced by a preference shift away from beef towards healthy alternatives. The net preference shift away from beef and towards these other products is zero. (Table N1.1 indicates the commodities making up the healthy set.)

N2. Simulation results

Revised simulations N1-N5

Tables N2.1 to N2.3 give results for the 5 revised simulations corresponding to the 5 simulations in the August report. The three tables divide the results into those for macro variables, commodity outputs and industry employment.

Simulations N1, N2 and N3

The results from simulations N1, N2 and N3 in Table N2.2 for beef processing output (commodity 32) are close to the corresponding results (those for Animal processing, com32) in Table 2.2 of the August report (-7.65, -7.57 and -7.64 compared with -7.56, -7.55 and -7.57). Ten per cent reductions in beef consumption have similar effects in simulations N1 to N3 on the output of Beef processing as 10 per cent reductions in consumption of Animal processing had in simulations 1 to 3 on the output of Animal processing. However, the effects on outputs of other commodities are distinctly different in Table N2.2 from the corresponding effects in Table 2.2. The reason is that a 10 per cent reduction in the consumption of Beef processing is effectively a smaller shock than a 10 per cent reduction in consumption of the more broadly defined commodity Animal processing. Thus, for example, the results for Fruit & vegetable canning (com 27) in simulations N1 – N3 are a scaled down version of those for simulations 1 – 3 (0.12, 1.20 and 0.40 compared with 0.56, 1.67 and 6.22).

Apart from Beef processing in the new simulations and Animal processing in the August simulations, downscaling is generally the pattern for output and employment results as we go from the August simulations 1 – 3 to the new simulations N1 – N3. However, there are many exceptions reflecting changes in our modeling. In the new simulation N3 concerned with meat alternatives, we have narrowed the definition of constituent meat replacement commodities from that adopted in the corresponding August simulation (3). Baseline consumption of meat alternative commodities in N3 is only about 1/8th of that in the old simulation (3). Consequently in the new simulation, output of meat replacement commodities is highly stimulated relative to what happened in the old simulation. For example, in N3 output of Flour malt milling (com 20) is increased by 7.426 per cent whereas in the old simulation the output increase for this commodity was only 1.672 per cent. Similarly for Fats & oils (com 23), the output increase in N3 is 14.729 per cent compared with 2.855 per cent in old simulation 3.

Reflecting the different size of the effective shock, we see that the macro results for simulations N1 and N2 in Table N2.1 are largely a scaled-down version of those for simulations 1 and 2 in Table 2.1. By contrast, there are some noticeable differences between the structure of the macro results for N3 in Table N2.1 and the corresponding results for simulation 3 in Table 2.1. The most obvious of these is the result for consumption of Food, 0.367 per cent in simulation N3, but only 0.015 per cent in simulation 3. We traced the difference in the food result first to the price of food. In simulation N3, the consumer price of food fell by 0.38 per cent whereas in simulation 3 it fell by only 0.03 per cent. In both simulations the overall price level of consumer goods was held constant. Consequently, in both simulations there was substitution towards food and away from non-food. With the reduction in the price of food being an order-of-magnitude greater in simulation N3 than in simulation 3 (0.38 compared with 0.03), the substitution effect towards food is much stronger in N3 than in 3. But why does the price of food fall more strongly in N3 than in 3? We traced this effect to the supply and demand for agricultural land. In both simulations, the total supply of agricultural land is fixed. In the August simulation 3, production of the meat replacement commodities is considerably more land intensive than in simulation N3. This is because in N3, we excluded Vegetables and Fruit & nuts from the replacement set, whereas they were included in August simulation 3. Both these commodities are land intensive. Their exclusion reduced the price of agricultural land in N3 relative to the price in the August simulation 3. This explains the stronger reduction in the price of food goods in simulation N3 relative to simulation 3.

Simulation N1 also exhibits a land-related difference from simulation 1. In simulation N1 the beef-tax required to reduce consumption by 10 per cent is 21.76 per cent. In simulation 1 it is 36.97 per cent. In simulation 1, the pre-tax price of the cattle-ranching product falls sharply because the rental price of cattle-ranching land falls sharply. This increases the tax rate that is necessary to reduce consumption by 10 per cent. In simulation N1 the fall in the price of cattle-ranching land is muted by land mobility introduced in improvement (d) above. Thus, in simulation N1, a lower rate of tax is sufficient to induce a 10 per cent reduction in consumption.

Simulations N4 and N5

To a large extent, simulation N4 is simply a scaled-down version of August simulation 4. The results in Tables N2.1 to N2.3 for simulation N4 are approximately 0.15 (= 0.5/3.32) times the corresponding results for simulation 4 in Tables 1.1 to 2.3.

The results for simulation N5 are very similar to those for simulation 5 in the August report. Improvements (a) to (d) make little difference to the model's projections of the effects of an increase in labor supply.

New simulations N6-N11

Simulation N6

Tables N2.4 to N2.6 give results for the 6 new simulations, N6 to N11. The tables divide the results into those for macro variables, commodity outputs and industry employment.

Comparing the results from simulation N6 with those from simulation N1 shows that using revenue from the beef tax to subsidize consumption of healthy foods produces slightly more unfavourable macro effects than simply returning the revenue to households in the form of a general tax cut. Table N2.4 for simulation N6 shows percentage reductions in GDP, private consumption and public consumption of 0.017, 0.021 and 0.022 whereas the corresponding percentage reductions in Table N2.1 for simulation N1 are 0.001, 0.003 and 0.003. In economic terms, subsidizing healthy foods introduces a distortion. It induces households to increase their consumption of commodities that they value less highly (the subsidized price) than the cost of producing them. Distortions such as this reduce GDP by causing capital, labor and land to be allocated to activities in which their contribution to GDP is relatively low.

Despite the small negative macro effects, subsidization of consumption of healthy foods might still be justified through health effects such as those illustrated in simulation N4 and N5 (see particularly Table N2.1). Comparison of results in Table N2.5 with those in Table N2.2, shows that subsidization of consumption of healthy foods leads to considerable increases in their output generated by increases in their consumption. The comparison is set out in Table N2.7.

Table N2. 1. Reduction in U.S. consumption of beef, cuts in health expenditures and increases in labor supply: macro effects in 2020 of policies implemented in 2015 (deviations from baseline)

		10% reduction in consumption of beef through a:			0.5% cut in health service requirements (Sim N4)	0.39% increase in labor supply (Sim N5)
		Beef tax (Sim N1)	Preference shift to all other food (Sim N2)	Preference shift to meat alternative (Sim N3)		
	Percentage changes					
1	Real GDP (Y)	-0.001	0.001	0.002	0.019	0.374
2	Real private consumption (C)	-0.003	0.000	0.000	0.014 (0.117)[a]	0.359
3	Real investment (I)	0.012	0.000	0.002	0.040	0.357
4	Real public consumption (G)	-0.003	0.000	0.000	0.014	0.362
5	Real exports (X)	0.003	0.018	0.035	0.051	0.350
6	Real imports (M)	0.004	0.008	0.020	0.046	0.256
7	Aggregate employment (L)	0.000	0.000	0.000	0.000	0.390
8	Aggregate capital (K)	0.019	0.005	0.009	0.042	0.360
9	Real wage (W/P_c)	-0.015	-0.002	-0.006	-0.008	0.060
10	Exchange rate (+ = appreciation)	-0.009	-0.006	-0.020	-0.020	-0.231
11	Price deflator for C (P_c)	0.000	0.000	0.000	0.000	0.000
12	Terms of trade	0.004	-0.006	-0.011	-0.016	-0.111
13	Consumption of food	-0.946	0.000	0.367	0.079	0.275
	Percentage point changes					
14	Trade balance, % of GDP	0.000	0.000	-0.001	-0.003	-0.007
15	Net f'gn liabilities, % of GDP	0.001	0.000	0.000	0.001	0.007

(a) This is the percentage increase in real consumption excluding health expenditure.

Table N2.2. Reduction in U.S. consumption of beef, cuts in health expenditures and increases in labor supply: industry/sector output effects in 2020 of policies implemented in 2015 (% deviations from baseline)

		10% reduction in consumption of beef through a:			0.5% cut in health service requirements (Sim N4)	0.39% increase in labor supply (Sim N5)
		Beef tax (Sim N1)	Preference shift to all other food (Sim N2)	Preference shift to meat alternative (Sim N3)		
1	Agriculture	-0.784	-0.618	-0.547	0.064	0.349
2	OilSeedFarm	0.171	0.246	1.860	0.042	0.274
3	GrainFarm	-0.272	-0.065	1.481	0.063	0.356
4	VegMelonFarm	0.008	0.936	0.106	0.067	0.353
5	FruitNutFarm	0.135	0.547	-0.015	0.047	0.273
6	GreenNursPrd	0.021	0.021	0.013	0.066	0.336
7	OthCropFarm	-0.287	-0.010	0.346	0.060	0.355
8	CattRancFarm	-6.966	-6.859	-6.990	0.062	0.353
9	DairCattProd	0.237	1.270	0.576	0.074	0.358
10	OtherAnimal	0.942	0.659	0.285	0.076	0.431
11	PoultryEgg	1.578	1.002	0.192	0.075	0.324
12	ForestLog	0.038	0.022	0.024	0.057	0.434
13	FishHuntTrap	0.774	0.388	0.087	0.067	0.383
14	AggSupportServ	-0.452	-0.187	0.342	0.059	0.357
15	Mining	0.016	0.003	0.016	0.040	0.277
16	Utilities	0.043	0.006	0.013	0.082	0.374
17	Construction	0.032	0.003	0.006	0.052	0.363
18	ManuOther	0.028	0.010	0.017	0.055	0.398
19	FoodManu	-0.904	-0.256	-0.278	0.074	0.347
20	FlourMaltMill	0.060	0.893	7.426	0.080	0.361
21	WetCornMill	0.154	0.550	2.799	0.068	0.380
22	SoyOilProc	0.178	0.496	3.633	0.067	0.353
23	FatsOils	0.014	0.919	14.729	0.076	0.328
24	BreakCereal	-0.030	1.082	0.126	0.080	0.343
25	SugarConfect	0.003	1.094	0.167	0.089	0.387
26	FrozFood	0.000	1.236	0.187	0.086	0.353
27	FrtVegCanning	0.116	1.195	0.399	0.073	0.362
28	…MilkButter	0.159	1.351	0.498	0.076	0.339

…Table N2.2 continues

Table N2.2 continued …'

		10% reduction in consumption of beef through a:			0.5% cut in health service requirements (Sim N4)	0.39% increase in labor supply (Sim N5)
		Beef tax (Sim N1)	Preference shift to all other food (Sim N2)	Preference shift to meat alternative (Sim N3)		
29	Cheese	0.348	1.334	0.734	0.077	0.377
30	DryCondEvapDairy	0.167	1.072	0.403	0.073	0.365
31	IceCream	0.670	1.652	1.311	0.012	0.362
32	BeefProc	-7.648	-7.569	-7.642	0.061	0.343
33	OthAnimProc	1.659	1.198	0.503	0.058	0.352
34	PoultryProc	1.668	1.007	0.227	0.076	0.331
35	Seafood	1.557	1.639	1.317	0.018	0.355
36	BreadBakery	0.058	1.202	0.305	0.086	0.348
37	CookiePasta	-0.007	1.237	0.231	0.084	0.329
38	SnackFood	-0.018	1.101	0.178	0.082	0.325
39	CoffTea	0.278	1.343	0.742	0.041	0.316
40	FlavorSyrup	0.252	0.673	0.433	0.093	0.431
41	SeasoningDressing	0.014	1.103	0.346	0.075	0.340
42	OthrFoodManu	-0.029	1.030	0.175	0.081	0.339
43	SoftDrinks[(a)]	0.036	0.006	-0.002	0.081	0.322
44	OtherServices	0.005	0.007	0.013	0.063	0.376
45	Health	0.051	0.001	0.002	-0.445	0.395
46	FoodServingSpecialists[(b)]	-0.083	0.002	0.004	0.119	0.395
47	AccHotels	0.024	0.001	0.003	0.111	0.392
48	FullRestaur	-0.122	0.003	0.006	0.113	0.395
49	LimRestaur	-0.089	0.002	0.004	0.126	0.396

(a) We classified Soft drink as part of Food manufacture. However, it was not included among food commodities (see Table N1.1)

(b) We classify 21 industries as food-serving specialists. Here we show results for the group as a whole and 3 major food-serving specialists.

Table N2.3. Reduction in U.S. consumption of beef, cuts in health expenditures and increases in labor supply: industry/sector employment effects in 2020 of policies implemented in 2015 (% deviations from baseline)

		10% reduction in consumption of beef through a:			0.5% cut in health service requirements (Sim N4)	0.39% increase in labor supply (Sim N5)
		Beef tax (Sim N1)	Preference shift to all other food (Sim N2)	Preference shift to meat alternative (Sim N3)		
1	Agriculture	-0.794	-0.524	-0.687	0.074	0.386
2	OilSeedFarm	0.133	0.280	2.308	0.061	0.361
3	GrainFarm	-0.340	-0.081	1.726	0.077	0.410
4	VegMelonFarm	-0.017	1.054	0.145	0.078	0.391
5	FruitNutFarm	0.089	0.600	0.040	0.062	0.343
6	GreenNursPrd	0.019	0.022	0.020	0.071	0.343
7	OthCropFarm	-0.348	-0.017	0.417	0.071	0.397
8	CattRancFarm	-7.582	-7.454	-7.575	0.070	0.379
9	DairCattProd	0.240	1.347	0.617	0.080	0.371
10	OtherAnimal	1.045	0.731	0.321	0.082	0.452
11	PoultryEgg	1.737	1.112	0.235	0.087	0.362
12	ForestLog	0.046	0.024	0.030	0.063	0.460
13	FishHuntTrap	0.877	0.438	0.101	0.074	0.409
14	AggSupportServ	-0.483	-0.189	0.415	0.065	0.374
15	Mining	0.025	0.005	0.027	0.057	0.381
16	Utilities	0.052	0.007	0.019	0.097	0.402
17	Construction	0.037	0.003	0.008	0.056	0.377
18	ManuOther	0.032	0.013	0.025	0.054	0.425
19	FoodManu	-0.897	-0.193	-0.551	0.079	0.363
20	FlourMaltMill	0.059	0.952	7.481	0.086	0.378
21	WetCornMill	0.152	0.536	2.694	0.071	0.405
22	SoyOilProc	0.172	0.544	4.428	0.073	0.375
23	FatsOils	-0.016	0.909	14.524	0.082	0.356
24	BreakCereal	-0.024	1.190	0.162	0.087	0.362
25	SugarConfect	0.003	1.177	0.188	0.096	0.408
26	FrozFood	-0.004	1.294	0.202	0.091	0.368
27	FrtVegCanning	0.130	1.255	0.426	0.078	0.378
28	…MilkButter	0.172	1.383	0.534	0.079	0.353

…Table N2.3 continues

Table N2.3 continued …'

		10% reduction in consumption of beef through a:			0.5% cut in health service requirements (Sim N4)	0.39% increase in labor supply (Sim N5)
		Beef tax (Sim N1)	Preference shift to all other food (Sim N2)	Preference shift to meat alternative (Sim N3)		
29	Cheese	0.353	1.402	0.759	0.082	0.391
30	DryCondEvapDairy	0.175	1.145	0.435	0.077	0.379
31	IceCream	0.707	1.762	1.392	0.015	0.379
32	BeefProc	-8.058	-7.975	-8.062	0.065	0.358
33	OthAnimProc	1.759	1.273	0.534	0.063	0.367
34	PoultryProc	1.715	1.018	0.196	0.081	0.344
35	Seafood	1.616	1.714	1.371	0.021	0.374
36	BreadBakery	0.070	1.348	0.343	0.090	0.358
37	CookiePasta	-0.005	1.321	0.209	0.090	0.345
38	SnackFood	-0.018	1.178	0.210	0.089	0.342
39	CoffTea	0.287	1.403	0.768	0.046	0.337
40	FlavorSyrup	0.279	0.784	0.494	0.101	0.460
41	SeasoningDressing	0.054	1.198	0.441	0.081	0.357
42	OthrFoodManu	-0.148	0.946	0.044	0.085	0.353
43	SoftDrinks[(a)]	0.045	0.024	0.016	0.086	0.339
44	OtherServices	0.012	0.009	0.016	0.047	0.383
45	Health	0.072	0.000	0.002	-0.470	0.406
46	FoodServingSpecialists[(b)]	-0.043	0.002	0.005	0.127	0.407
47	AccHotels	0.048	0.001	0.003	0.132	0.409
48	FullRestaur	-0.064	0.003	0.006	0.117	0.404
49	LimRestaur	-0.063	0.001	0.004	0.135	0.409

(a) We classified Soft drink as part of Food manufacture. However, it was not included among food commodities (see Table N1.1)

(b) We classify 21 industries as food-serving specialists. Here we show results for the group as a whole and 3 major food-serving specialists.

Table N2.4. Reduction in U.S. consumption of beef: macro effects in 2020 of policies implemented in 2015 (deviations from baseline)

		10% reduction in consumption of beef through a:		30% cut in consumption of beef through a:	30% cut in consumption of beef through a:	60% cut in consumption of beef through a:	15% cut in consumption of beef through a:
		Beef tax & subsidy on healthy food (Sim N6)	Beef tax & increase in public expenditure (Sim N7)	Beef tax with revenue returned to households (Sim N8)	Pref. shift away from beef to meat alternatives (Sim N9)	Pref. shift away from beef to meat alternatives (Sim N10)	Pref. shift away from beef to healthy food (Sim N11)
	Percentage changes						
1	Real GDP (Y)	-0.017	-0.013	-0.044	0.006	0.016	-0.003
2	Real private consumption (C)	-0.021	-0.149	-0.058	0.001	0.005	-0.007
3	Real investment (I)	-0.015	0.008	0.033	0.008	0.019	-0.008
4	Real public consumption (G)	-0.022	0.560	-0.058	0.001	0.005	-0.007
5	Real exports (X)	0.084	0.039	0.011	0.109	0.233	0.080
6	Real imports (M)	0.038	-0.062	0.020	0.062	0.132	0.036
7	Aggregate employment (L)	0.000	0.000	0.000	0.000	0.000	0.000
8	Aggregate capital (K)	-0.015	-0.004	0.055	0.030	0.069	-0.003
9	Real wage (W/P_c)	-0.031	-0.129	-0.099	-0.016	-0.031	-0.013
10	Exchange rate (+ = appreciation)	-0.059	0.093	-0.003	-0.060	-0.116	-0.035
11	Price deflator for C (P_c)	0.000	0.000	0.000	0.000	0.000	0.000
12	Terms of trade	-0.027	-0.010	0.013	-0.035	-0.076	-0.028
13	Consumption of food	0.398	-1.043	-3.227	1.025	1.816	0.054
	Percentage point changes						
14	Trade balance, % of GDP	-0.002	0.017	-0.001	-0.003	-0.006	-0.001
15	Net f'gn liabilities, % of GDP	-0.001	0.000	0.002	0.000	0.000	0.000

Table N2.5. Reduction in U.S. consumption of beef:
industry/sector output effects in 2020 of policies implemented in 2015 (% deviations from baseline)

		10% reduction in consumption of beef through a:		30% cut in consumption of beef through a:	30% cut in consumption of beef through a:	60% cut in consumption of beef through a:	15% cut in consumption of beef through a:
		Beef tax & subsidy on healthy food (Sim N6)	Beef tax & increase in public expenditure (Sim N7)	Beef tax with revenue returned to households (Sim N8)	Pref. shift away from beef to meat alternatives (Sim N9)	Pref. shift away from beef to meat alternatives (Sim N10)	Pref. shift away from beef to healthy food (Sim N11)
1	Agriculture	-0.408	-0.821	-2.108	-1.614	-3.126	-1.014
2	OilSeedFarm	0.309	0.171	0.550	5.515	10.811	0.343
3	GrainFarm	-0.161	-0.297	-0.686	4.405	8.673	-0.319
4	VegMelonFarm	4.611	-0.045	0.029	0.314	0.609	4.832
5	FruitNutFarm	2.137	0.120	0.376	-0.058	-0.154	2.321
6	GreenNursPrd	-0.010	-0.022	0.057	0.041	0.082	0.016
7	OthCropFarm	-0.512	-0.306	-0.819	1.028	2.015	-0.399
8	CattRancFarm	-6.937	-6.973	-20.802	-20.889	-41.408	-10.429
9	DairCattProd	-0.430	0.173	0.918	1.719	3.404	0.913
10	OtherAnimal	1.068	0.875	3.353	0.849	1.679	0.416
11	PoultryEgg	1.689	1.472	5.571	0.575	1.147	0.319
12	ForestLog	0.062	0.041	0.131	0.072	0.139	0.050
13	FishHuntTrap	0.928	0.744	2.697	0.261	0.515	0.146
14	AggSupportServ	0.002	-0.458	-1.261	1.009	1.961	-0.157
15	Mining	0.026	0.009	0.058	0.049	0.099	0.014
16	Utilities	-0.016	-0.049	0.127	0.040	0.082	0.002
17	Construction	-0.014	0.020	0.090	0.018	0.041	-0.002
18	ManuOther	0.053	0.015	0.103	0.051	0.103	0.031
19	FoodManu	-0.674	-0.970	-2.486	-0.806	-1.505	-0.886
20	FlourMaltMill	1.525	-0.009	0.264	22.041	43.292	1.845
21	WetCornMill	0.930	0.121	0.592	8.329	16.410	1.114
22	SoyOilProc	0.883	0.152	0.709	10.672	20.699	0.860
23	FatsOils	3.885	-0.057	0.102	43.677	85.747	3.279
24	BreakCereal	-0.885	-0.104	-0.079	0.372	0.731	0.228

…Table N2.5 continues

Table N2.5 continued …

		10% reduction in consumption of beef through a:		30% cut in consumption of beef through a:	30% cut in consumption of beef through a:	60% cut in consumption of beef through a:	15% cut in consumption of beef through a:
		Beef tax & subsidy on healthy food (Sim N6)	Beef tax & increase in public expenditure (Sim N7)	Beef tax with revenue returned to households (Sim N8)	Pref. shift away from beef to meat alternatives (Sim N9)	Pref. shift away from beef to meat alternatives (Sim N10)	Pref. shift away from beef to healthy food (Sim N11)
25	SugarConfect	-0.799	-0.071	0.040	0.500	0.993	0.331
26	FrozFood	-0.926	-0.091	0.030	0.572	1.171	0.392
27	FrtVegCanning	6.978	0.066	0.482	1.188	2.342	5.636
28	MilkButter	-0.668	0.111	0.634	1.485	2.937	0.783
29	Cheese	-0.286	0.253	1.330	2.187	4.322	1.119
30	DryCondEvapDairy	-0.457	0.133	0.651	1.212	2.415	0.663
31	IceCream	0.197	0.608	2.564	3.901	7.684	1.963
32	BeefProc	-7.608	-7.652	-22.858	-22.845	-45.312	-11.413
33	OthAnimProc	1.871	1.584	5.833	1.496	2.951	0.762
34	PoultryProc	1.826	1.555	5.896	0.673	1.315	0.356
35	Seafood	1.626	1.466	5.623	3.920	7.726	1.994
36	BreadBakery	-0.811	-0.023	0.259	0.915	1.822	0.493
37	CookiePasta	-0.983	-0.104	0.010	0.694	1.384	0.364
38	SnackFood	-0.945	-0.104	-0.045	0.544	1.098	0.308
39	CoffTea	-0.098	0.217	1.090	2.207	4.349	1.386
40	FlavorSyrup	1.170	0.178	0.947	1.293	2.556	1.473
41	SeasoningDressing	-0.144	-0.057	0.166	1.021	1.986	0.989
42	OthrFoodManu	-0.649	-0.108	-0.040	0.530	1.066	0.480
43	SoftDrinks(a)	-0.022	-0.061	0.088	-0.005	-0.005	0.008
44	OtherServices	-0.011	0.008	-0.002	0.039	0.078	0.011
45	Health	-0.064	-0.112	0.106	0.006	0.014	0.000
46	FoodServingSpecialists(b)	-0.180	-0.220	-0.396	0.014	0.028	0.004
47	AccHotels	-0.067	-0.091	0.027	0.009	0.020	0.000
48	FullRestaur	-0.221	-0.269	-0.551	0.019	0.038	0.007
49	LimRestaur	-0.189	-0.228	-0.423	0.011	0.024	0.003

(a) We classified Soft drink as part of Food manufacture. However, it was not included among food commodities (see Table N1.1)

(b) We classify 21 industries as food-serving specialists. Here we show results for the group as a whole and 3 major food-serving specialists.

Table N2.6. Reduction in U.S. consumption of beef: industry/sector employment effects in 2020 of policies implemented in 2015 (% deviations from baseline)

		10% reduction in consumption of beef through a:		30% cut in consumption of beef through a:	30% cut in consumption of beef through a:	60% cut in consumption of beef through a:	15% cut in consumption of beef through a:
		Beef tax & subsidy on healthy food (Sim N6)	Beef tax & increase in public expenditure (Sim N7)	Beef tax with revenue returned to households (Sim N8)	Pref. shift away from beef to meat alternatives (Sim N9)	Pref. shift away from beef to meat alternatives (Sim N10)	Pref. shift away from beef to healthy food (Sim N11)
1	Agriculture	-0.070	-0.836	-2.138	-2.040	-3.992	-0.606
2	OilSeedFarm	0.555	0.132	0.486	6.877	13.575	0.526
3	GrainFarm	-0.103	-0.368	-0.853	5.145	10.164	-0.316
4	VegMelonFarm	5.299	-0.077	-0.031	0.432	0.847	5.521
5	FruitNutFarm	2.556	0.070	0.269	0.112	0.192	2.705
6	GreenNursPrd	-0.003	-0.026	0.056	0.059	0.116	0.021
7	OthCropFarm	-0.512	-0.368	-0.979	1.239	2.438	-0.411
8	CattRancFarm	-7.502	-7.589	-22.482	-22.499	-44.098	-11.293
9	DairCattProd	-0.450	0.172	0.946	1.841	3.640	0.968
10	OtherAnimal	1.206	0.971	3.735	0.955	1.887	0.467
11	PoultryEgg	1.951	1.618	6.173	0.705	1.409	0.386
12	ForestLog	0.090	0.048	0.164	0.089	0.171	0.065
13	FishHuntTrap	1.065	0.844	3.065	0.301	0.593	0.171
14	AggSupportServ	0.044	-0.490	-1.329	1.234	2.439	-0.130
15	Mining	0.051	0.018	0.096	0.081	0.161	0.026
16	Utilities	0.000	-0.057	0.164	0.056	0.110	0.009
17	Construction	-0.005	0.026	0.109	0.024	0.050	0.001
18	ManuOther	0.070	0.028	0.121	0.074	0.147	0.043
19	FoodManu	-0.695	-0.968	-2.468	-1.634	-3.189	-0.859
20	FlourMaltMill	1.494	-0.013	0.279	22.292	44.011	1.860
21	WetCornMill	0.927	0.124	0.590	8.037	15.888	1.101
22	SoyOilProc	1.108	0.142	0.695	13.109	25.662	1.047
23	FatsOils	3.809	-0.087	0.034	43.422	86.063	3.217
24	BreakCereal	-0.713	-0.102	-0.048	0.479	0.939	0.434

Table N2.6 continues

Table N2.6 continued …

		10% reduction in consumption of beef through a:		30% cut in consumption of beef through a:	30% cut in consumption of beef through a:	60% cut in consumption of beef through a:	15% cut in consumption of beef through a:
		Beef tax & subsidy on healthy food (Sim N6)	Beef tax & increase in public expenditure (Sim N7)	Beef tax with revenue returned to households (Sim N8)	Pref. shift away from beef to meat alternatives (Sim N9)	Pref. shift away from beef to meat alternatives (Sim N10)	Pref. shift away from beef to healthy food (Sim N11)
25	SugarConfect	-0.857	-0.074	0.047	0.561	1.112	0.354
26	FrozFood	-0.963	-0.099	0.024	0.616	1.255	0.412
27	FrtVegCanning	7.074	0.078	0.539	1.271	2.520	5.780
28	MilkButter	-0.586	0.122	0.688	1.593	3.147	0.872
29	Cheese	-0.313	0.257	1.357	2.263	4.471	1.157
30	DryCondEvapDairy	-0.474	0.140	0.690	1.304	2.597	0.717
31	IceCream	0.220	0.642	2.713	4.144	8.173	2.093
32	BeefProc	-7.990	-8.061	-23.945	-23.976	-47.115	-12.010
33	OthAnimProc	2.005	1.680	6.198	1.591	3.137	0.819
34	PoultryProc	1.896	1.597	6.112	0.589	1.182	0.312
35	Seafood	1.656	1.522	5.846	4.084	8.056	2.057
36	BreadBakery	-0.904	-0.013	0.309	1.029	2.049	0.554
37	CookiePasta	-1.036	-0.106	0.024	0.636	1.287	0.398
38	SnackFood	-0.984	-0.110	-0.036	0.635	1.273	0.344
39	CoffTea	-0.080	0.224	1.130	2.287	4.508	1.451
40	FlavorSyrup	1.265	0.201	1.056	1.474	2.913	1.644
41	SeasoningDressing	-0.014	-0.020	0.306	1.336	2.683	1.189
42	OthrFoodManu	-0.779	-0.227	-0.388	0.138	0.295	0.281
43	SoftDrinks[(a)]	0.030	-0.054	0.126	0.048	0.098	0.058
44	OtherServices	0.016	0.051	0.033	0.048	0.093	0.018
45	Health	-0.044	-0.107	0.188	0.007	0.015	0.002
46	FoodServingSpecialists[(b)]	-0.143	-0.191	-0.245	0.015	0.030	0.006
47	AccHotels	-0.051	-0.098	0.111	0.010	0.020	0.004
48	FullRestaur	-0.162	-0.215	-0.326	0.018	0.037	0.007
49	LimRestaur	-0.167	-0.209	-0.327	0.013	0.027	0.005

(a) We classified Soft drink as part of Food manufacture. However, it was not included among food commodities (see Table N1.1)

(b) We classify 21 industries as food-serving specialists. Here we show results for the group as a whole and 3 major food-serving specialists.

Table N2.7. Comparison of output results: healthy foods not subsidized, N1, and subsidized, N6 (percentage effects)

Healthy foods	Simulation N1	Simulattion N6
VegMelonFarm	0.008	4.6
FruitNutFarm	0.135	2.1
FlourMillMalt	0.060	1.5
WetCornMill2	0.154	0.9
SoyOilseedProc	0.178	0.9
FatsOils	0.014	3.9
FrtVegCanning	0.116	7.0

A final noteworthy comparison between simulations N6 and N1 is the results for food consumption (row 13 in Tables N2.1 and N2.4). Subsidization of healthy foods in N6 encourages substitution of food for non-food products. Thus, a possibly unanticipated side effect of subsidization is to move the percentage deviation result for food in N1 from -0.946 to +0.398 in N6.

Simulation N7

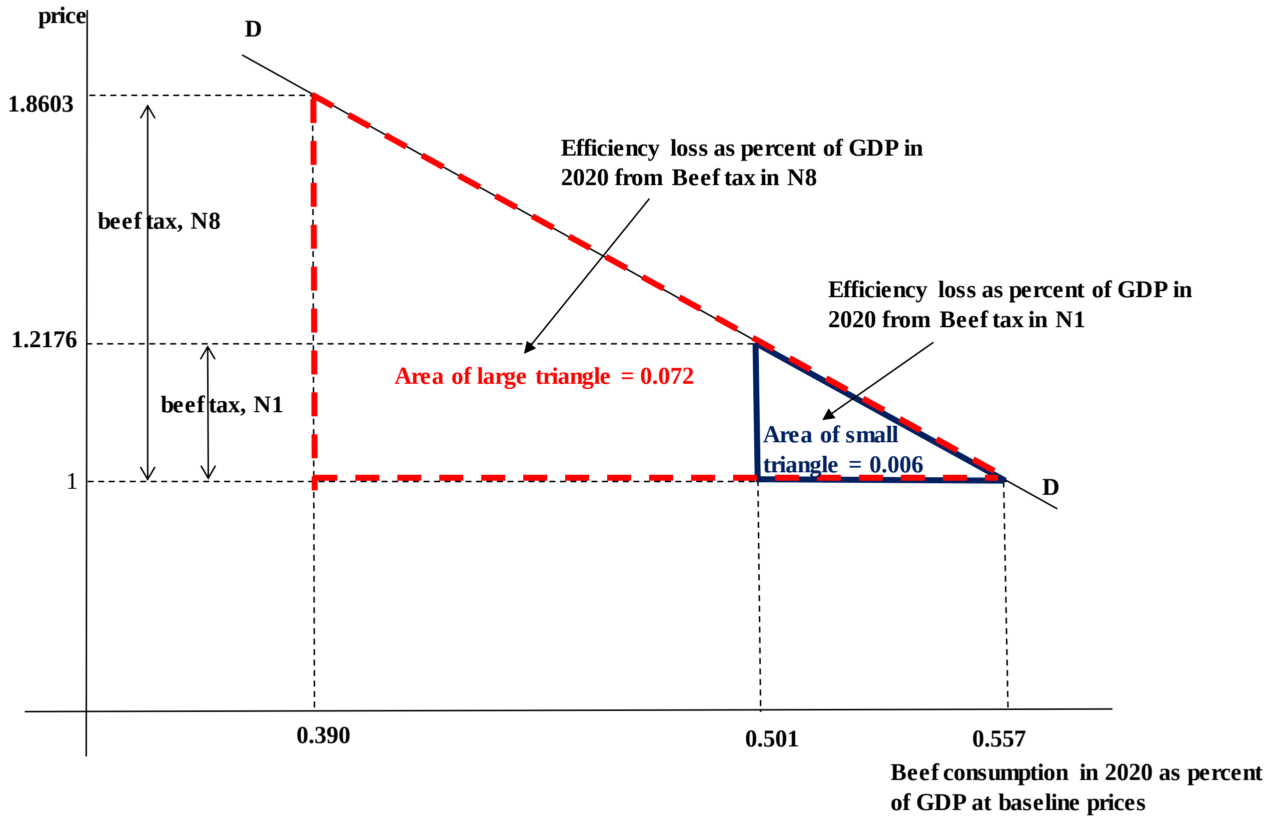
Comparing the results from simulation N7 with those from simulation N1 shows the effects of substituting public consumption for private consumption. In N1, the effects on both public and private consumption of the beef tax with the revenue returned to households are small (-0.003 per cent, Table N2.1, rows 2 and 4). In N7, public consumption rises by 0.560 per cent while private consumption falls by 0.149 per cent. These movements in public and private consumption are broadly offsetting with regard to total demand. However, differences in the composition of public and private consumption cause minor differences in macro results. Private consumption is considerably more import-intensive than public consumption. Thus, for N7 we see a negative effect on aggregate imports (-0.062 per cent) whereas for N1 the import effect is a negligible positive (0.004 per cent). Production of goods and services for private consumption is more capital intensive than production for public consumption. Thus for N7 we see a negative effect for aggregate capital (-0.004 per cent) whereas in N1 the effect is positive (0.019 per cent). With lower private consumption in N7 than in N1, consumption of food is reduced, from a deviation of -0.946 per cent in N1 to -1.043 per cent in N7.

The effects on the results for commodity outputs and industry employment of the switch from private to public consumption as we go from N1 to N7 are small. With lower private consumption in N7, the output and employment results for most consumer commodities and industries are slightly lower for N7 than for N1.

Simulation N8

As a first guess, we might expect the results for simulation N8 to be similar to those for N1 scaled-up by a factor of three: the only difference between the setups of the two simulations is that the beef tax in N8 is calibrated to produce a 30 per cent reduction in beef consumption whereas in N1 the reduction is only 10 per cent. While scaling-up by a factor of three works reasonably well for most of the non-negligible commodity output and industry employment results, it breaks down for the macro results.

Figure N2.1. Demand for beef and efficiency losses from beef taxes in N1 and N8



DD is a stylized representation of household demand in USAGE-Food for beef in 2020, either through direct purchases or through food serving organizations such as restaurants. In the baseline, household beef consumption valued at untaxed prices accounts for 0.557 per cent of GDP. Simulations N1 and N8 imply that taxes of 21.76 per cent and 86.03 per cent reduce the quantity of consumption by 10 per cent and 30 per cent. In the figure, this is expressed as reductions in beef consumption from 0.557 per cent of baseline GDP to 0.501 per cent (N1) and 0.390 per cent (N8). In calculating 0.501 and 0.390 we used the baseline price for beef.

The GDP effect in N8 is much more negative than would be expected on the basis of a factor of 3 applied to the N1 result (-0.044 per cent in N8 compared with -0.001 per cent in N1). Most of the extra GDP loss in N8 is caused by an efficiency loss. As illustrated in Figure N2.1, the efficiency loss associated with taxing beef increases roughly with the square of the rate of the distorting tax. Because of non-linearity in demand (not shown in Figure N2.1), the tax rate in N8 is more than three times that in N1 (86.03 per cent compared with 21.76 per cent). Thus, the efficiency loss in N8 is more than 9 times that in N1.

With the GDP result in N8 being scaled up much more than three times relative to that in N1, the results for associated macro variables in N8 are also scaled up by much more than three times. For example, public and private consumption in N8 decline by 0.058 per cent whereas in N1 they decline by only 0.003 per cent.

The general conclusion from the comparison of simulations N8 and N1 is that the macro-economic cost of reducing beef consumption through a tax goes up steeply for each per cent reduction. As illustrated in Figure N2.1, the first 10 percent reduction can be achieved at an efficiency cost of 0.006 percent of GDP, but the cost of the next 20 per cent reduction is 0.066 per cent of GDP (= 0.072 - 0.006).

Simulations N9 and N10

Simulations N9 and N10 are similar to N3 except that the preference shifts in N9 and N10 are calibrated to produce reductions in beef consumption of 30 per cent and 60 per cent instead of 10 per cent. Unlike tax increases, preference shifts do not cause non-linear efficiency effects. Consequently, to a good approximation, the results for N9 and N10 are scaled-up versions of those for N3 with the scaling factors being 3 and 6.

Simulation N11

Simulation N11 is similar to N3, except the preference shift is towards healthy foods rather than meat alternatives. Another difference between the two simulations is that the preference shift in N11 is calibrated to cause a reduction in the consumption of beef of 15 per cent rather than 10 per cent.

In our database, the share of capital in labor plus capital for production of healthy foods (listed in Table N1.1) is 0.257, whereas for Beef processing it is 0.334. Thus, in N11 the shift away from Beef processing towards healthy foods is capital reducing (-0.003, Table N2.4, row 8). By contrast the share of capital in capital plus labor in the production of meat alternatives (also listed in Table N1.1) is 0.539. Thus, in N3 the shift away from Beef processing towards meat alternatives is capital increasing (0.009, Table N2.1, row 8). The difference in the capital results between N11 and N3 is the main explainer of the difference in GDP results (-0.003 in N11 compared with 0.002 for N3).

At the commodity/industry level, the percentage reduction in the output of Beef processing is about 1.5 times larger in N11 than in N3 (-11.413 in N11 compared with -7.642 in N3, row 32 in Tables N2.5 and N2.2). This reflects the shock of 15 per cent in N11 compared with 10 per cent in N3. For other commodities/industries the differences in the results reflect the differences between the healthy food set and the meat alternatives set. For example, in N11 the output VegMelon farming increases by 4.832 per cent (Table N2.5, row 4). In N3, the output of VegMelon farming increases by only 0.106 per cent (Table N2.2, row 4). The difference is that VegMelon farming is part of the healthy food set, but not part of the meat alternatives set.

N3. Concluding remarks

In any project, it is impossible to conduct and analyse all of the potentially interesting simulations. However, readers can take results from simulations that *are* reported and calculate approximate results for simulations that *are not* reported. This can be done by making linear combinations of results of reported simulations. While this approach is generally legitimate, care must be taken with GDP results arising in tax simulations. As we saw in the comparison of simulation N8 with N1, using a beef tax to reduce beef consumption by 30 per cent is much more than three times as damaging to GDP as using a a beef tax to reduce beef consumption by 10 per cent.

However, if the beef tax is held constant then combining a beef tax simulation with a scaled preference simulation is broadly legitimate. For example, we might be interested in the possibility of the effects of a beef tax (N6) coinciding with a preference shift (N11). By adding results from N6 to those from N11 we can approximate the results for a combined N6 & N11 simulation. In this combined simulation, a beef tax is imposed which, by itself, would reduce beef consumption by 10 per cent. The revenue from this tax is used to subsidize consumption of healthy food commodities. At the same time, there is a preference shift against beef that, by itself, would reduce beef consumption by 15 per cent. The preference shift against beef is balanced by a preference shift towards health food commodities.

To a reasonable approximation the combined simulation would show a 25 per cent reduction in beef consumption balanced by strong increases in the output and consumption of healthy foods. For example, we would expect the combined simulation to show an increase in VegMelon farming of 9.44 per cent (= 4.61 +4.83).

Appendix N1. The theory of nesting and its application in USAGE-Food

Production functions

In standard versions of USAGE, industry production functions have 3 levels of nests. At the first level, output of an industry is a function of Composite genuine input and Other costs. Composite genuine input consists of primary factors and materials. Using these inputs, uses up resources. Other costs are an artificial input used to fill in discrepancies between the total observed cost of inputs and the observed value of output. At the second level, Composite genuine input is a function of Primary-factor input and inputs of intermediates undifferentiated by source. At the third level, Primary-factor input is a function of labor, capital and land, and undifferentiated intermediates are functions of domestic and imported varieties.

To allow substitution effects in USAGE-Food in industries such as restaurants between different commodity inputs from the food sector, we modify the production functions to allow for 5 levels of nests. The two extra levels allow for substitution within the food product between Flesh and Non-Flesh, and then within each of Flesh and Non-flesh substitution between different types of flesh (beef, poultry, etc) and substitution between different type of Non-Flesh (vegetables, fruit, grains, etc).

Here we start by setting out the general theory of input demand arising from cost-minimization subject to a 5-level nested production in which all nests are CES. Then we consider the particular nesting structure in USAGE-Food.

Production function with 5-level CES nests: general case.

$$X0 = CES1\left(\frac{X1(i)}{A1(i)} \quad i = 1,...,C1\right) \tag{L1P}$$

$$X1(i) = CES2\left(\frac{X2(i,f)}{A2(i,f)} \quad f = 1,...,C2(i)\right) \text{ for i = 1, ..., C1} \tag{L2P}$$

$$X2(i,f) = CES3\left(\frac{X3(i,f,k)}{A3(i,f,k)} \quad k = 1,...,C3(i,f)\right) \text{ for i = 1, ..., C1 and f = 1, ..., C2(i)} \tag{L3P}$$

$$X3(i,f,k) = CES4\left(\frac{X4(i,f,k,s)}{A4(i,f,k,s)} \quad s = 1,...,C4(i,f,k)\right) \tag{L4P}$$

for i = 1, ..., C1; f = 1, ..., C2(i); k = 1, ..., C3(i,f)

$$X4(i,f,k,s) = CES5\left(\frac{X5(i,f,k,s,h)}{A5(i,f,k,s,h)} \quad h = 1,...,C5(i,f,k,s)\right)$$

for i = 1, ..., C1; f = 1, ..., C2(i); k = 1, ..., C3(i,f), s=1, ...,C4(i,f,k) (L5P)

X0 is total inputs to production in an industry.

X1(i) is the i^{th} level-1 input that creates total input. C1 is the number of items at level 1.

X2(i,f) is the f^{th} input in the nest at level 2 that creates the i item at level 1. C2(i) is the number of items in the nest at level 2 that create the i item in level 1.

X3(i,f,k) is the k^{th} input in the nest at level 3 that creates the (i,f) item at level 2. C3(i,f) is the number of items in the nest at level 3 that create the (i,f) item in level 2.

X4(i,f,k,s) is the sth input in the nest at level 4 that creates the (i,f,k) item at level 3. C4(i,f,k) is the number of items in the nest at level 4 that create the (i,f,k) item in level 3.

X5(i,f,k,s,h) is the hth input in the nest at level 5 that creates the (i,f,k,s) item at level 4. C5(i,f,k,s) is the number of items in the nest at level 5 that create the (i,f,k,s) item in level 4.

The A's are input-saving or using technical change or taste change variables.

Input-demand functions in percentage change form

Under cost-minimizing assumptions, we obtain:

$$x1(i) - a1(i) = x0 - \sigma1\left(p1(i) - \sum_{t\in C1} S1(t)*p1(t)\right) - \sigma1\left(a1(i) - \sum_{t\in C1} S1(t)*a1(t)\right) \quad \text{for } i = 1,\ldots,C1 \tag{1}$$

$$p1(i) = \sum_{f\in C2(i)} S2(i,f)*p2(i,f) + \sum_{f\in C2(i)} S2(i,f)*a2(i,f) \quad \text{for } i = 1,\ldots,C1 \tag{2}$$

$$\begin{aligned} x2(i,f) - a2(i,f) = x1(i) &- \sigma2(i)\left(p2(i,f) - \sum_{t\in C2(i)} S2(i,t)*p2(i,t)\right) \\ &- \sigma2(i)\left(a2(i,f) - \sum_{t\in C2(i)} S2(i,t)*a2(i,t)\right) \\ &\text{for } i = 1,\ldots,C1; f = 1,\ldots,C2(i) \end{aligned} \tag{3}$$

$$\begin{aligned} p2(i,f) = \sum_{k\in C3(i,f)} S3(i,f,k)*p3(i,f,k) + \sum_{k\in C3(i,f)} S3(i,f,k)*a3(i,f,k) \\ \text{for } i = 1,\ldots,C1; f = 1,\ldots,C2(i) \end{aligned} \tag{4}$$

$$\begin{aligned} x3(i,f,k) - a3(i,f,k) = x2(i,f) &- \sigma3(i,f)\left(p3(i,f,k) - \sum_{t\in C3(i,f)} S3(i,f,t)*p3(i,f,t)\right) \\ &- \sigma3(i,f)\left(a3(i,f,k) - \sum_{t\in C3(i,f)} S3(i,f,t)*a3(i,f,t)\right) \\ &\text{for } i = 1,\ldots,C1; f = 1,\ldots,C2(i); k = 1,\ldots,C3(i,f) \end{aligned} \tag{5}$$

$$\begin{aligned} p3(i,f,k) = \sum_{s\in C4(i,f,k)} S4(i,f,k,s)*p4(i,f,k,s) + \sum_{s\in C4(i,f,k)} S4(i,f,k,s)*a4(i,f,k,s) \\ \text{for } i = 1,\ldots,C1; f = 1,\ldots,C2(i); k = 1,\ldots,C3(i,f) \end{aligned} \tag{6}$$

$$\begin{aligned} x4(i,f,k,s) - a4(i,f,k,s) = x3(i,f,k) \\ - \sigma4(i,f,k)\left(p4(i,f,k,s) - \sum_{t\in C4(i,f,k)} S4(i,f,k,t)*p4(i,f,k,t)\right) \\ - \sigma4(i,f,k)\left(a4(i,f,k,s) - \sum_{t\in C4(i,f,k)} S4(i,f,k,t)*a4(i,f,k,t)\right) \\ \text{for } i = 1,\ldots,C1; f = 1,\ldots,C2(i); k = 1,\ldots,C3(i,f); s = 1,\ldots,C4(i,f,k) \end{aligned} \tag{7}$$

$$\begin{aligned} p4(i,f,k,s) = \sum_{h\in C5(i,f,k,s)} S5(i,f,k,s,h)*p5(i,f,k,s,h) + \sum_{s\in C5(i,f,k,s)} S5(i,f,k,s,h)*a5(i,f,k,s,h) \\ \text{for } i = 1,\ldots,C1; f = 1,\ldots,C2(i); k = 1,\ldots,C3(i,f); s = 1,\ldots,C4(i,f,k) \end{aligned} \tag{8}$$

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$$x5(i,f,k,s,h) - a5(i,f,k,s,h) = x4(i,f,k,s)$$
$$- \sigma5(i,f,k,s)\left(p5(i,f,k,s,h) - \sum_{t \in C5(i,f,k,s)} S5(i,f,k,t) * p5(i,f,k,s,t) \right)$$
$$- \sigma5(i,f,k,s)\left(a5(i,f,k,s,h) - \sum_{t \in C5(i,f,k,s)} S5(i,f,k,t) * a4(i,f,k,s,t) \right)$$
$$\text{for } i = 1,...,C1; f = 1,...,C2(i); k = 1,...,C3(i,f); s = 1,...,C4(i,f,k); h = 1,...,C5(i,f,k,s) \quad (9)$$

In these equations the lowercase x, a and p variables refer to percentage changes in quantities, prices and technology variables. The uppercase S's refer to cost shares which can be computed from input-output data. S1(i) is the share of level-1 input i in the cost of all level-1 inputs, e.g. the share of Composite genuine input in the total cost of Composite genuine input and Other cost. S2(i,f) is the share in the total cost of level-1 input i accounted for by the f^{th} input in the nest at level 2 that makes up level-1 input i. S3(i,f k) is the share in the total cost of level-2 input (i,f) accounted for by the k^{th} input in the nest at level 3 that makes up level-2 input (i,f). S4(i,f,k,s) is the share in the total cost of level-3 input (i,f,k) accounted for by the s^{th} input in the nest at level 4 that makes up level-3 input (i,f,k). S5(i,f,k,s,h) is the share in the total cost of level-4 input (i,f,k,s) accounted for by the h^{th} input in the nest at level 5 that makes up level-4 input (i,f,k,s). The parameters σ1, σ2(i), σ3(i,f), σ4(i,f,k) and σ5(i,f,k,s) are substitution elasticities occurring in the 5 nests.

5-level nesting for production functions in USAGE-Food

Figure A3.1 indicates the nesting structure in the production function for an industry in USAGE-Food. Table A3.1 records how many items appear in each nest.

X0 is total input for the industry.

Total input is created by a combination of 2 items at level 1. These two items are Composite genuine input and Other costs, denoted by X1(1) and X1(2). Thus, C1 = 2, see Table A3.1. This is the number of items at level 1 that go to make up total input.

Because there are two items at level 1 there must be 2 nests at level 2. In USAGE-Food, the first nest at level 2, that is the nest that creates the first item at level 1, contains C2(1) items. These items are: Primary factor, denoted by X2(1,1); Composite food, denoted by X2(1,2); and C2(1) -2 other intermediate inputs, denoted by X2(1,3), ..., X2(1,C2(1)). The second nest at level 2 contains just one item [C2(2) = 1]. This is simply Other costs repeated from level 1 but now denoted by X2(2,1), that is the quantity of the first (and only) input at level 2 that makes up the second input at level 1.

Because there are C2(1)+C2(2) items at level 2 there must be C2(1)+C2(2) nests at level 3 and because C2(2) = 1, Figure A3.1 shows C2(1)+1 nests at level 3. In USAGE-Food, the first nest at level 3, that is the nest that creates the first item [X2(1,1)] at level 2, contains three items [that is C3(1,1) =3]. These items are the constituents of Primary factors, namely labor, capital and land, denoted by X3(1,1,1), ..., X3(1,1,C3(1,1)). The second nest at level 3, that is the nest that creates the second item [X2(1,2)] at level 2 contains 2 items [C3(1,2) = 2]. The 2 items are sub-categories of Food: Flesh and Non-Flesh. The next C2(1)-2 nests at level 3 each contain only one item, which is simply a renamed input-output commodity from level 2. The final nest in level 3 contain only one item, which is simply Other costs renamed from level 2 as X3(2,1,1).

Because there are $C3(1,1)+C3(1,2)+\sum_{k=3}^{C2(1)} C3(1,k)+C3(2,1)$ items at level 3 there must be the same number of nests at level 4. The first C3(1,1) of these nests each contain just one item. The item in the first of these nests is Labor renamed as X4(1,1,1,1). The item in the second nest is Capital, renamed as X4(1,1,2,1). The item in the C3(1,1) nest, that is the third nest, is Land, renamed as X4(1,1,C3(1,1),1). In our notation, C4(1,1,k) = 1 for k = 1, …C3(1,1).

The next two nests at level 4 [C3(1,2)=2] comprise input-output food commodities. There are 6 input-output commodities in the first, corresponding to the Flesh sub-category of Food and 21 in the second, corresponding to the Non-flesh sub-category of Food (see Table 1.1) [1].

The next C2(1)-2 nests at level 4 [corresponding to $\sum_{k=3}^{C2(1)} C3(1,k)$] each contain only one item, which is simply a renamed item from level 3: X4(1,3,1,1), X4(1,4,1,1), …, X4(1,C2(1),1,1).

The final nest in level 4 contain only one item, which is simply Other costs renamed from level 3 as X4(2,1,1,1).

Because there are $\sum_{k=1}^{C3(1,1)} C4(1,1,k)+C4(1,2,1)+C4(1,2,2)+\sum_{k=3}^{C2(1)} C4(1,k,1)+C4(2,1,1)$ items at level 4 there must be the same number of nests at level 5. The first $\sum_{k=1}^{C3(1,1)} C4(1,1,k)$ of these nests each contains just one primary factor item, renamed from level 4. The next $C4(1,2,1)+C4(1,2,2)$ $+\sum_{k=3}^{C2(1)} C4(1,k,1)$ nests each have two items, the domestic and imported versions of the corresponding input-output commodities identified in level 4. Consider for example, the input-output commodity Flour. The two associated items in level 5 are:

X5("Composite genuine", "Food", "Non-Flesh", "flour", "domestic") and
X5("Composite genuine", "Food", "Non-Flesh", "flour", "imported").

In our notation, C5(1,2,3,k) = 2 for k = Flour.

[1] As indicated in footnote 3 to Table 1.1, in one of our simulations the food nest contains only 11 items.

Figure A3.1. Nesting assumptions for an industry production function in USAGE-Food:

(A). Symbolic representation

LEVEL0	LEVEL1	LEVEL2	LEVEL3	LEVEL4	LEVEL5
X0	X1(1)	X2(1,1)	X3(1,1,1)	X4(1,1,1,1)	X5(1,1,1,1,1)
			X3(1,1,2)	X4(1,1,2,1)	X5(1,1,2,1,1)
			X3(1,1,C3(1,1))	X4(1,1,C3(1,1),1)	X5(1,1,C3(1,1),1,1)
		X2(1,2)	X3(1,2,1)	X4(1,2,1,1)	X5(1,2,1,1,1)
					X5(1,2,1,1,2)
				…	…
				X4(1,2,1,C4(1,2,1))	X5(1,2,1,C4(1,2,1,1))
					X5(1,2,1,C4(1,2,1),2)
			X3(1,2,2)	X4(1,2,2,1)	X5(1,2,2,1,1)
					X5(1,2,2,1,2)
				…	…
				X4(1,2,2,C4(1,2,2))	X5(1,2,2,C4(1,2,2),1)
					X5(1,2,2,C4(1,2,2),2)
		X2(1,3)	X3(1,3,1)	X4(1,3,1,1)	X5(1,3,1,1,1)
					X5(1,3,1,1,2)
		…	…	…	…
		X2(1,C2(1))	X3(1,C2(1),1)	X4(1,C2(1),1,1)	X5(1,C2(1),1,1,1)
					X5(1,C2(1),1,1,2)
	X1(2)	X2(2,1)	X3(2,1,1)	X4(2,1,1,1)	X5(2,1,1,1,1)

(B). Contents of each nest

LEVEL0	LEVEL1	LEVEL2	LEVEL3	LEVEL4	LEVEL5
All input	Composite				
	genuine	Prim Fac	Labour	Labour	Labour
			Capital	Capital	Capital
			land	land	land
		Food	Flesh	io com	io com dom
					io com by imp
				…	…
				io com	io com dom
					io com by imp
			Non flesh	io com	io com dom
					io com by imp
				…	…
				io com	io com dom
					io com by imp
		io com	io com	io com	io com dom
					io com by imp
		…	…	…	…
		io com	io com	io com	io com dom
					io com by imp
	Other costs	Other costs	Other costs	Other costs	Other costs

Table A3.1. Number of items in the production function nests in USAGE-Food

LEVEL1	LEVEL2	LEVEL3	LEVEL4	LEVEL5
C1=2	C2(1)= 367[(a)]	C3(1,1) = 3[(b)]	C4(1,1,k)=1 for $k \in$ C3(1,1)	C5(1,1,k,1)=1 for $k \in$ C3(1,1)
		C3(1,2) = 2[(b)]	C4(1,2,1)=6[(c)]	C5(1,2,1,k)=2 for $k \in$ C4(1,2,1)
			C4(1,2,2)=21[(c)]	C5(1,2,2,k)=2 for $k \in$ C4(1,2,2)
		C3(1,k)=1[(b)] for k = 3, …, C2(1)	C4(1,k,1)=1 for k = 3, …, C2(1)	C5(1,k,1,1)=2 for all k= 3, … C2(1)
	C2(2)= 1	C3(2,1)=1	C4(2,1,1)= 1	C5(2,1,1,1)=1

(a) USAGE-Food identifies 392 commodities at the input-output level (see Table A2.1). Of these, 27 are food items (see Table 1.1). Thus, there are 366 commodity inputs at level 2, 365 commodities defined at the input-output level plus Food. These commodity inputs feed into the Genuine input X1(1). The composite primary factor input also appears in the level 2 nest that makes the composite Genuine input. Thus, C2(1) = 367.
(b) The 367 items in C2(1) are split into 365 input-output commodities; and 2 FOOD commodities (Flesh and Non flesh); and 3 primary factor commodity.
(c) The first FOOD commodity is split into the 6 Flesh commodities and the second FOOD commodity is split into the 21 Non flesh food commodities

Utility function

In specifying household demands for commodities in USAGE-Food, we use a 4-level utility function: Stone-Geary at the top level with 3 underlying CES nests:

$$U = \sum_i B(i) * \ln\left(\frac{X1(i)}{Q} - G(i)\right) \qquad (L1U)$$

$$X1(i) = CES2\left(\frac{X2(i,f)}{A2(i,f)} \quad f = 1,...,C2(i)\right) \text{ for } i = 1, ..., C1 \qquad (L2U)$$

$$X2(i,f) = CES3\left(\frac{X3(i,f,k)}{A3(i,f,k)} \quad k = 1,...,C3(i,f)\right) \text{ for } i = 1, ..., C1 \text{ and } f = 1, ..., C2(i) \qquad (L3U)$$

$$X3(i,f,k) = CES4\left(\frac{X4(i,f,k,s)}{A4(i,f,k,s)} \quad s = 1,...,C3(i,f,k)\right) \qquad (L4U)$$

for i = 1, ..., C1, f = 1, ..., C2(i) and k = 1, ..., C3(i,f)

where
Q is number of households;
B(i) is the marginal budget share for commodity i;
G(i) is the household per capita subsistence requirement of commodity i;
X1(i) is total household consumption of level-1 commodity i;
X2(i,f) is total household consumption of level-2 commodity i,f, the f^{th} commodity in the nest that generates level-1 commodity i;

X3(i,f,k) is total household consumption of level-3 commodity i,f,k, the k^{th} commodity in the nest that generates level-2 commodity i,f; and

X4(i,f,k,s) is total household consumption of level-4 commodity i,f,k,s, the s^{th} commodity in the nest that generates level-3 commodity i,f,k; and

the A's are preference-change variables.

Figure A3.2 indicates the particular nesting structure in USAGE-Food. U is total utility specified by L(1). Total utility is created by a combination of 366 items at level 1. These are per household consumption of 365 non-food input-output commodities denoted by X1(1) to X1(365), and composite food denoted by X1(366). Thus, C1 = 366. This is the number of items at level 1 that go to make up total utility.

Because there are 366 items at level 1 there must be 366 nests at level 2. In USAGE-Food, the first 365 nests at level 2, that is the nests that create the first 365 items at level 1, each contain a single item denoted by X2(i,1), i = 1, …, 365. Thus, C2(i) =1 for all i = 1, …, 365. The last nest at level 2 contains the 2 food items: Flesh and Non-Flesh. Thus C2(366) = 2.

Because there are 367 items at level 2 there must be 367 nests at level 3. In USAGE-Food, the first 365 nests at level 3, that is the nests that create the first 365 items at level 2, each contain a single item denoted by X3(i,1,1), i = 1, …, 365. Thus, C3(i,1) =1 for all i = 1, …, 365. The next nest at level 3 contains the 6 flesh items and the last nest contains 21 non-flesh items. Thus C3(366,1) = 6 and C3(366,2) = 21.

Because there are 392 items at level 4, Figure A3.2 shows 392 nests at level 3. Each of these nests has two items. The two items are the domestic and imported versions of the level-3 input-output commodity.

Optimization of level-1: cost minimization subject to Stone-Geary utility constraint

For any given level of utility U, households

choose X1(1), …, X1(C1)

to minimize $\sum_i \text{P1(i)} * \text{X1(i)}$

subject to $\text{U} = \sum_i \text{B(i)} * \ln\left(\frac{\text{X1(i)}}{\text{Q}} - \text{G(i)}\right)$

First order conditions:

$$\text{P1(i)} = \Lambda * \text{B(i)} * \frac{1/\text{Q}}{\text{X1(i)}/\text{Q} - \text{G(i)}} \qquad (10)$$

where Λ is the Lagrangian multiplier.

Rearrange (10) as

$$\text{P1(i)} * \left[\text{X1(i)}/\text{Q} - \text{G(i)}\right] = \frac{\Lambda * \text{B(i)}}{\text{Q}} \qquad (11)$$

Sum over i

$$\frac{\text{Y}}{\text{Q}} - \sum_i \text{P1(i)} * \text{G(i)} = \frac{\Lambda}{\text{Q}} \qquad (12)$$

where Y = $\sum_i \text{P1(i)} * \text{X1(i)}$, that is Y is the household budget.

Substitute (12) into (11). This gives the well known linear expenditure system:

$$\frac{X1(i)}{Q} = G(i) + \frac{B(i)}{P1(i)} * \left[\frac{Y}{Q} - \sum_j P1(j) * G(j) \right] \tag{13}$$

In percentage change form (13) can be written as

$$\frac{X1(i)}{Q} * \left(x1(i) - q \right) = 100 * dG(i) + \frac{B(i)}{P1(i)} * \frac{Y}{Q} * \left(\beta(i) + y - p1(i) - q \right)$$
$$- \left\{ \frac{B(i)}{P1(i)} * \sum_j P1(j) * G(j) \right\} * \left(\beta(i) - p1(i) \right) - \frac{B(i)}{P1(i)} * \left\{ \sum_j P1(j) * G(j) * \left[p1(j) \right] + 100 * \sum_j P1(j) * dG(j) \right\} \tag{14}$$

where variables denoted by lowercase symbols are percentage changes in variables denoted by the corresponding uppercase symbols. Notice that we use the change form, dG(i), for G(i). This is because G(i) can be of either sign and may move through zero.

After a considerable amount of tedious but elementary algebra we find that (14) can be rewritten as

$$\left(x1(i) - q \right) = \varepsilon(i) * \left(y - q \right) + \sum_j \eta(i, j) * p1(j)$$
$$+100 * Q * dG(i) / X1(i) - \varepsilon(i) * 100 * \sum_j S1(j) * Q * dG(j) / X1(j) - \varepsilon(i) \frac{1}{F} * \beta(i) \tag{15}$$

where $S1(i) = \frac{P1(i) X1(i)}{Y}$ (16)

$$F = \frac{-Y / Q}{Y / Q - \sum_j P1(j) * G(j)} \tag{17}$$

$\varepsilon(i) = \frac{B(i)}{S1(i)}$ and (18)

$$\eta(i, j) = KD(i, j) * \frac{\varepsilon(i)}{F} - \varepsilon(i) * S1(j) * \left(1 + \frac{\varepsilon(j)}{F} \right) \tag{19}$$

S1(i) is the share of i in household expenditure.

F is the negative of the reciprocal of the share of supernumerary expenditure in household expenditure. F is known as the Frisch coefficient.

$\eta(i, j)$ is the elasticity of household demand for commodity i with respect to a change in the price of commodity j.

$\varepsilon(i)$ is the expenditure elasticity of household demand for commodity i.

Preference variables

Equation (15) contains two preference-change variables for each of the C1 commodities at level 1. These can be written as $Q * dG(j) / X1(j)$ and $\beta(j)$. In effect, we reduce this to C1 preference changes by connecting $Q * dG(i) / X1(i)$ and $\beta(i)$ via C1 new variables a1com(i). We do this by writing:

$$\beta(i) = a1com(i) - \sum_k B(k) * a1com(k) \tag{20}$$

and

$$Q * dG(i) / X1(i) = 0.01\left(1+\frac{\varepsilon(i)}{F}\right)*\left[a1com(i) - \sum_k S1(k) * a1com(k)\right] \qquad (21)$$

If we set a1com(i) at -1, then via (20) and (21) we are imposing a taste change against commodity i of about 1 per cent by reducing both the subsistence and supernumerary consumption of i by about 1 per cent. Not surprisingly as demonstrated below, under (20) and (21), (15) reduces to

$$\left(x1(i)-q\right) = \varepsilon(i)*\left(y-q\right) + \sum_j \eta(i,j)*p1(j) + a1com(i)) - \sum_k S1(k)*a1com(k) \qquad (22)$$

To demonstrate (22), we start by substituting from (20) and (21) into (15) to obtain

$$\begin{aligned}\left(x1(i)-q\right) &= \varepsilon(i)*\left(y-q\right) + \sum_j \eta(i,j)*p1(j)\\ &+\left(1+\frac{\varepsilon(i)}{F}\right)*\left[a1com(i)-\sum_k S1(k)*a1com(k)\right]\\ &-\varepsilon(i)*\sum_j S1(j)*\left(1+\frac{\varepsilon(j)}{F}\right)*\left[a1com(j)-\sum_k S1(k)*a1com(k)\right]\\ &-\varepsilon(i)\frac{1}{F}*\left(a1com(i)-\sum_k B(k)*a1com(k)\right)\end{aligned} \qquad (23)$$

We rewrite (23) with all of the preference expressions broken into individual terms:

$$\begin{aligned}\left(x1(i)-q\right) &= \varepsilon(i)*\left(y-q\right) + \sum_j \eta(i,j)*p1(j)\\ &+a1com(i)+\frac{\varepsilon(i)}{F}*a1com(i)-\sum_k S1(k)*a1com(k)-\frac{\varepsilon(i)}{F}*\sum_k S1(k)*a1com(k)\\ &-\varepsilon(i)*\sum_j S1(j)*a1com(j)-\varepsilon(i)*\sum_j S1(j)*\frac{\varepsilon(j)}{F}*a1com(j)\\ &-\varepsilon(i)*\sum_j S1(j)*\sum_k S1(k)*a1com(k)+\varepsilon(i)*\sum_j S1(j)*\frac{\varepsilon(j)}{F}*\sum_k S1(k)*a1com(k)\\ &-\varepsilon(i)*\frac{1}{F}*a1com(i)+\varepsilon(i)*\frac{1}{F}*\sum_k B(k)*a1com(k)\end{aligned} \qquad (24)$$

Then we apply three identities: equation (18); sum of shares equal 1; and the share-weighted sum of expenditure elasticities equals 1. This yields (22).

Consumer demand functions in percentage change form

The complete 4-nest household demand system in percentage change form, similar to the GEMPACK specification in USAGE-Food, is:

$$x1(i)-q = \varepsilon(i)*\left(c-q\right)+\sum_j \eta(i,j)*p1(j)+a1com(i)-ave\_a1com \quad \text{for } i = 1, 2, \ldots, C1 \qquad (25)$$

$$ave\_a1com = \sum_k S1(k)*a1com(k) \quad , \qquad (26)$$

$$p1(j) = \sum_{f\in C2(j)} S2(j,f)*p2(j,f) + \sum_{f\in C2(j)} S2(j,f)*a2(j,f) \quad \text{for } j = 1,\ldots,C1 \qquad (27)$$

$$x2(i,f) - a2(i,f) = x1(i) - \sigma2(i)\left(p2(i,f) - \sum_{t \in C2(i)} S2(i,t) * p2(i,t) \right)$$

$$- \sigma2(i)\left(a2(i,f) - \sum_{t \in C2(i)} S2(i,t) * a2(i,t) \right) \qquad (28)$$

$$\text{for } i = 1,\ldots,C1; f = 1,\ldots,C2(i)$$

$$p2(i,f) = \sum_{k \in C3(i,f)} S3(i,f,k) * p3(i,f,k) + \sum_{k \in C3(i,f)} S3(i,f,k) * a3(i,f,k) \qquad (29)$$

$$\text{for } i = 1,\ldots,C1; f = 1,\ldots,C2(i);$$

$$x3(i,f,k) - a3(i,f,k) = x2(i,f) - \sigma3(i,f)\left(p3(i,f,k) - \sum_{t \in C3(i,f)} S3(i,f,t) * p3(i,f,t) \right)$$

$$- \sigma3(i,f)\left(a3(i,f,k) - \sum_{t \in C3(i,f)} S3(i,f,t) * a3(i,f,t) \right) \qquad (30)$$

$$\text{for } i = 1,\ldots,C1; f = 1,\ldots,C2(i); k = 1,\ldots,C3(i,f)$$

$$p3(i,f,k) = \sum_{s \in C4(i,f,k)} S4(i,f,k,s) * p4(i,f,k,s) + \sum_{s \in C4(i,f,k)} S4(i,f,k,s) * a4(i,f,k,s) \qquad (31)$$

$$\text{for } i = 1,\ldots,C1; f = 1,\ldots,C2(i); k = 1,\ldots,C3(i,f);$$

$$x4(i,f,k,s) - a4(i,f,k,s) = x3(i,f,k) - \sigma4(i,f,k)\left(p4(i,f,k,s) - \sum_{t \in C4(i,f,k)} S4(i,f,k,t) * p4(i,f,k,t) \right)$$

$$- \sigma4(i,f,k)\left(a4(i,f,k,s) - \sum_{t \in C4(i,f,k)} S4(i,f,k,t) * a4(i,f,k,t) \right)$$

$$\text{for } i = 1,\ldots,C1; f = 1,\ldots,C2(i); k = 1,\ldots,C3(i,f); s = 1,\ldots,C4(i,f,k) \qquad (32)$$

where the S coefficients are shares derived from household expenditure data in the input-output tables. These are defined by

$$S4(i,f,k,t) = \frac{V(i,f,k,t)}{\sum_{tt \in C3(i,f,k)} V(i,f,k,tt)}$$

$$S3(i,f,k) = \frac{\sum_{t \in C4(i,f,k)} V(i,f,k,t)}{\sum_{kk \in C3(i,f)} \sum_{t \in C4(i,f,k)} V(i,f,kk,t)}$$

$$S2(i,f) = \frac{\sum_{k \in C3(i,f)} \sum_{t \in C4(i,f,k)} V(i,f,k,t)}{\sum_{ff \in C2(i)} \sum_{k \in C3(i,f)} \sum_{t \in C4(i,f,k)} V(i,ff,k,t)}$$

where V(i,f,k,t) is household expenditure on domestic or imported (t) input-output commodity (i,f,k). For example, expenditure on domestic Flour is written as V(Food,Non-Flesh, Flour, domestic), and expenditure on imported cars is written as V(cars, cars, cars,imported).

Figure A3.2. Nesting assumptions for consumer utility in USAGE-Food:

(A). Symbolic representation

LEVEL0	LEVEL1	LEVEL2	LEVEL3	LEVEL4
U	X1(1)	X2(1,1)	X3(1,1,1)	X4(1,1,1,1) X4(1,1,1,2)
	…	…	…	…
	X1(C1(1))	X2(C1(1),1)	X3(C1(1),1,1)	X4(C1(1),1,1,1) X4(C1(1),1,1, 2)
	X1(2)	X2(2,1)	X3(2,1,1)	X4(2,1,1,1) X4(2,1,1,2)
			…	…
			X3(2,1,C3(2,1))	X4(2,1,C3(2,1),1) X4(2,1,C3(2,1),2)
		X2(2,2)	X3(2,2,1)	X4(2,2,1,1) X4(2,2,1,2)
			…	…
			X3(2,2,C3(2,2))	X4(2,2,C3(2,2),1) X4(2,2,C3(2,2),2)

(B). Contents of each nest

LEVEL0	LEVEL1	LEVEL2	LEVEL3	LEVEL4
Utility	io com	io com	io com	io com dom io com imp
	…	…	…	…
	io com	io com	io com	io com dom io com imp
	Food	Flesh	io com	io com dom io com imp
			…	…
			io com	io com dom io com imp
		Non flesh	io com	io com dom io com imp
			…	…
			io com	io com dom io com imp

Table A3.2. Number of items in the consumer nests in USAGE-Food

LEVEL1	LEVEL2	LEVEL3	LEVEL4
C1=366	C2(k)=1 for k = 1, …, 365	C3(k,1)=1 for k = 1, …, 365	C4(k,1,1)=2 for k = 1, …, 365
	C2(366)=2 for k =366	C3(366,1) = 6	C4(366,1.k)=2 for k∈ C3(366,1)
		C3(366,2) = 21	C4(366,2,k)=2 or k∈ C3(366,2)

PART 2

Computable general equilibrium simulations of the effects on the U.S. economy of reductions in beef consumption: preliminary results

By Peter B. Dixon and MaureenT. Rimmer

Centre of Policy Studies, Victoria University

August 1, 2019

(Slightly revised December 19, 2019)

Summary

(1) The CSIRO and Johns Hopkins are researching the effects of reducing beef consumption in the U.S. To support this work, the Centre of Policy Studies at Victoria University has undertaken to perform relevant simulations with the USAGE model of the U.S. economy. This is a preliminary report on those simulations.

(2) USAGE is a dynamic computable general equilibrium (CGE) model identifying 392 industries/commodities. The model has been widely used by and on behalf of agencies of the U.S. government in Washington DC.

(3) For this project, we have modified standard USAGE to create USAGE-Food. The modified model emphasises substitution possibilities between different food products.

(4) We have used USAGE-Food to create 5 building blocks for the analysis of beef-reducing policies. These building blocks are simulations that show the effects on macro and industry variables of:

(5) a reduction in beef consumption brought about by a beef tax;

(6) a reduction in beef consumption caused by a preference shift against beef towards other food products in general;

(7) a reduction in beef consumption caused by a preference shift against beef towards a particular set of food products that we call a veggie burger;

(8) a reduction in requirements for health services that we imagine could be associated with a diet-related improvement in the health of the U.S. population; and

(9) an increase in labor-force participation that we imagine could be associated with a diet-related improvement in the health of the U.S. population.

(10) We hope that the CSIRO/Johns-Hopkins team will provide weights that can be used to combine effects calculated under (a) to (e) in the assessment of specific beef-reducing policies.

(11) Building block simulations (a), (b) and (c) show that the macroeconomic effects of reducing beef consumption in favor of other commodities is likely to be minor. However, for a given percentage reduction in beef consumption, the simulations show distinct structural effects. The beef-tax simulation gives the biggest reduction in agricultural output. followed by the veggie burger simulation, followed by the general preference simulation.

(12) By contrast, with simulations (a) to (c), simulations (d) and (e) show that the macroeconomic effects of reducing health-service requirement and increasing labor-force participation can be large.

(13) We have made a considerable effort in the report to explain, in an understandable way, the data items and assumption that are important in determining the results. We hope that this will facilitate discussion with the CSIRO/Johns-Hopkins team.

CONTENTS

Computable general equilibrium simulations of the effects on the U.S. economy of reductions in beef consumption: preliminary results

By Peter B. Dixon and MaureenT. Rimmer

Centre of Policy Studies, Victoria University

August 1, 2019

As a contribution to a CSIRO-Johns -Hopkins project on the effects of reductions in beef consumption, the Centre of Policy Studies has undertaken to provide 5 sets of computable general equilibrium (CGE) simulations. These will be conducted with the USAGE model and will quantify the effects on the U.S. economy of:

(1) reductions in beef consumption brought about by the imposition of beef taxes;
(2) reductions in beef consumption brought about by changes in consumer preferences caused by a successful consumer awareness program;
(3) promotion of beef substitutes made from plant-based inputs (veggie burger);
(4) reductions in health expenditures to reflect improved health associated with reduced consumption of beef;
(5) increased work force participation rates associated with improved health arising from reduced consumption of beef.

This paper has three parts. First we give a brief overview of CGE modeling in general and the USAGE model in particular. Then we provide preliminary results for (1) to (5). The final section outlines steps that will be necessary to move from preliminary to final results.

1. Background on CGE modeling and USAGE

CGE belongs to the economy-wide class of models, that is, those that provide industry disaggregation in a quantitative description of the whole economy. Economy-wide models emphasize the links between different parts of the economy. The first economy-wide model was Leontief's (1936, 1941) input-output model, which quantified links between industries as suppliers and customers for each other's products. In Leontief's world, an increase in household demand for cars stimulates the motor vehicle industry, which in turn stimulates the steel industry, which in turn stimulates the iron ore and coal industries, etc. Following Leontief, the next stage of economy-wide modeling was the programming models of Sandee (1960), Manne (1963), Evans (1972) and others.

Input-output and programming models lacked clear descriptions of the behaviour of individual agents. In input-output modeling, the economy organized production of each commodity (the vector X) to satisfy a vector of final demands (the vector Y) with given technology specified by the input-output coefficient matrix (A). In programming models, the economy organized production to maximize a welfare function subject to Leontief's technology specification and subject to constraints on the availability of primary factors.

CGE modeling started with Johansen (1960). By contrast with the earlier economy-wide models, Johansen's CGE model identified behaviour by individual agents. Households in CGE models maximize utility subject to their budget constraint. Industries choose inputs to minimize costs subject to production-function constraints and the need to satisfy demands for their outputs. Capitalists allocate capital between industries to maximize their returns. The overall outcome for the economy is determined by the actions of individual agents co-ordinated through price adjustments that equalize demand and supply in product and factor markets.

Relative to input-output and linear programming models, CGE models are an effective framework for understanding how different parts of the economy are linked. CGE models go much further than supply/customer links. CGE models emphasize links provided by competition for scarce resources: labor in different skill categories; capital; and land. As originally recognized by Johansen, an industry may be harmed by the expansion of other industries through shortages of labor and capital. Johansen's CGE model balanced the benefits of Leontief's supply/customer links against the inhibiting effects of increases in the costs of labor and capital. Modern CGE models emphasize links occurring through the exchange rate which connects import-competing and export-oriented industries. This is important in analyzing tariff policy. With cuts in protection, import-competing industries contract, lowering the exchange rate and allowing expansion of export-oriented industries. Another link encapsulated by modern CGE models is through the public-sector budget and competition for scarce public funds.

Because of their flexibility and realism, CGE models have gradually become the dominant form of economy-wide model. Over the last 50 years, they have been used in the analysis of an enormous variety of questions. These include:

the effects on

- macro variables, including measures of nation-wide or even global economic welfare;
- industry variables;
- regional variables;
- labor market variables;
- distributional variables; and
- environmental variables

of

- taxes, tariffs and public expenditures;
- environmental policies;
- technology developments;
- changes in international commodity prices and interest rates;
- labor market policies and union behavior;
- exploitation of mineral deposits (the Dutch disease); and
- terrorism and other disruptive events.

Although CGE modeling has proved valuable in policy analysis, it has met considerable resistance from parts of the economics profession. There is a feeling that CGE models are black boxes. This is understandable because the theory, data and computational requirements for CGE models are daunting relative to those for input-output models. In an effort to increase accessibility of CGE modeling, its practitioners have been active in providing textbooks[2] and training not only for economists but also for policy advisors. CoPS and Purdue University's Global Trade Analysis Project (GTAP) are prominent training providers with courses in many parts of the world including Washington DC.

[2] See, for example, Burfisher (2011).

CGE modellers have also worked hard to increase the transparency of their results through a variety of means including back-of-the-envelope (BOTE) justifications that can be readily understood by people without CGE backgrounds (see, for example, Dixon and Rimmer, 2013). In qualitative terms, the pure theory of CGE modeling suggests that every result depends on every assumption and data item through a system of simultaneous equations. However, in quantitative terms, for any given set of results there is always a small number of key determining assumptions and data items. By identifying these through BOTE analyses, CGE modelers provide a basis for assessing results and answering questions such as: are the key assumptions and data items plausible; and how would the results be affected if we changed a particular assumption or data item. In this report, we provide BOTE explanation of results from our five preliminary simulations. We hope to communicate in a way that dispels the black-box perception.

1.1 The USAGE model

USAGE is a detailed CGE model of the U.S. economy, developed over the last 15 years at the Centre of Policy Studies. It has been applied in a large number of studies, by and on behalf of: the U.S. International Trade Commission; the U.S. Departments of Commerce, Homeland Security, Agriculture, Energy and Transportation; the Canadian Government; and private sector organizations in the U.S. such as the Mitre Corporation and the Cato Institute. Topics include: terrorism; stimulus policy; trade; immigration; energy; transport infrastructure spending; model validation; model development; and health. USAGE publications are listed in Appendix 1.

Features that USAGE shares with most other single-country CGE models are that:

- industries and capital creators choose intermediate and primary factor inputs to minimize the costs of supplying any given amounts of output and new capital subject to constant-returns-to-scale production functions with CES nests;
- households choose their consumption bundle to maximize utility subject to factor incomes plus transfers less taxes;
- all agents treat domestic and imported varieties of any commodity as imperfect substitutes in the fashion of Armington (1969);
- exporters face downward sloping demand curves for their products;
- commodity and factor prices in each period are determined by the interaction of demand and supply;
- the quantity of capital created for each industry responds to expected rates of return formed using either forward-looking or static specifications; and
- the economy evolves from period to period driven by capital accumulation and exogenously given paths for population, technology, consumer preferences, world trading conditions and policy objectives.

Unlike most other CGE models, USAGE assesses the effects of a policy by comparing the path of the economy with the policy in place with an explicit baseline path, without the policy. Thus, a simulation of the effects of a policy shock requires two runs of the model: the baseline run and a policy run. The baseline run is intended to be a plausible forecast. It builds in macro and energy forecasts from the U.S. Energy Information Administration and trends in other variables such as technology and preferences [see, for example. Dixon *et al.* (2017)]. Policy runs generate deviations away from the baseline caused by policies under consideration. For this project, these policies encapsulate beef-consumption-reduction programs and related cuts in health expenditures and increases in labor-force participation.

For the most part, we report the effects of policies as percentage deviations in variables (such as outputs and employment) away from their baseline paths.

As can be seen from USAGE publications (Appendix 1), there are different versions of USAGE. These versions start from a core model and are modified to facilitate particular applications. For example, for applications concerned with illegal immigration, the model's labor market specification was expanded to allow for legal and unauthorized workers in 50 occupations. In applications concerned with road infrastructure, the model's industry specification was expanded to allow for Hired trucking, In-house trucking, Private road transport, Commuter car travel, Vacation car travel, Car repairs, and Highways & bridges.

For this project, we have created a version of the model that we refer to as USAGE-Food. This version has 392 industries/commodities. These are listed in Appendix 2. Results reported at the 392-level can be overwhelming. Although the computations are conducted at this level, for reporting results in section 2, we aggregate. Tables A2.1 and A2.2 in Appendix 2 show the aggregation schemes.

In creating USAGE-Food, we have modified the core model by adding Food nests in the household utility function. These facilitate the analysis of policies that cause households to shift their consumption from one food commodity (Beef products in this project) to other food commodities. Direct purchasers by households account for only about 63 per cent of the sales of Beef products in the U.S. (excluding intra-industry sales). Another 28 per cent occurs via industries such as restaurants, hospitals and colleges that serve food. The remainder goes to industries such as pet food. To allow for changes in the commodity composition of served food, we added food nests to industry production functions. Table 1.1 lists the commodities in the food nests and the industries that we identified as food servers. Appendix 3 sets out the theory of nested utility and production functions and shows how it has been applied in USAGE-Food.

2. USAGE simulations relevant to assessing the effects on the U.S. economy of reduced beef consumption in the U.S.: preliminary results

Tables 2.1 to 2.3 give results for 5 USAGE simulations corresponding to (1) to (5) listed in the introduction. All of the results are policy-induced deviations from baseline values in 2020 caused by policies that we imagine to be implemented in 2015.

Simulations 1 to 3 show effects of a 10 per cent reduction in beef consumption caused by: (1) the imposition of taxes; (2) a shift in preferences away from beef towards other food products in general; and (3) a shift in preferences away from beef towards specific other food products, namely vegetable intensive beef substitutes (veggie burgers).

Simulation 4 shows the effects of a reduction in health-service requirements of 3.32 per cent. This is 10 per cent of health expenditure made on behalf of people in the age group 45-64. We suspect that this is the age group for which improved diet might lead to the greatest flow-on to reduced health expenditures.

Simulation 5 shows the effect of an increase in labor supply of 0.39 per cent. This would be the effect on labor supply if people in the 45-64 age group increased their labor force participation by 1 per cent. People in this age group account for 39 per cent of U.S. employment. At the same time, they are the people whose labor-force participation rates are the most sensitive to health status.

Table 1.1. Commodities in food nests and industries that serve food[1]

Food commodities	Food coms mapped to two subcategories	Food serving industries
VegMelonFarm[2]	Non-flesh	RetailTrade
FruitNutFarm[2]	Non-flesh	EleSecSchool
PoultryEgg[2]	Flesh	Colleges
FishHuntTrap[2]	Flesh	Hospitals
FlourMillMalt[2]	Non-flesh	NursingHome
WetCornMill[2]	Non-flesh	MentlHealth
SoyOilseedProc[2]	Non-flesh	SocialSvce
FatsOils[2]	Non-flesh	ChildCare
BreakCereal[2]	Non-flesh	SpectSports[3]
SugarConfec	Non-flesh	Promoters
FrozFood	Non-flesh	MuseumZoo[3]
FrtVegCanning[2]	Non-flesh	AmusePark[3]
MilkButter	Non-flesh	OthAmuse
Cheese	Non-flesh	AccomHotels
DryCondEvapDairy	Non-flesh	FullRestaur
IceCream	Non-flesh	LimRestaur
BeefProc	Flesh	ReligiousOrg
OthAnimProc	Flesh	FedGovDef
PoultryProc	Flesh	FedElecUtil
Seafood	Flesh	OthFedGovEnt
BreadBakery	Non-flesh	StateLocGov
CookiePasta	Non-flesh	Holiday
SnackFood	Non-flesh	ExportTour
CoffTea	Non-flesh	ExportEdu
FlavorSyrup	Non-flesh	OthNonResident
SeasDressing	Non-flesh	
OthrFoodManu	Non-flesh	

1. Descriptions of USAGE-Food commodities and industries are in Table A2.1 (Appendix 2).
2. These eleven commodities make up the food set in simulation 3 in which 10% of beef consumption is replaced by a vegetable-intensive product (veggie burger) rather than food in general.
3. We had to exclude these three industries from the food serving group in simulation 3 because they do not purchase any of the 10 meat-substitute commodities identified in that simulation.

We should emphasize that the percentage shocks (three 10 per cents and 3.32 & 0.39 per cent) mentioned in these descriptions of the five simulations will need to fine tuned. The present numbers are essentially arbitrary. Nevertheless, we think they are suggestive. Although USAGE is not a linear model, effects of other shocks can be reasonably well approximated by scaling. For example, readers interested in the effects of a 5 per cent reduction in beef consumption will not be seriously misled if they halve the results from simulations 1, 2 and 3. Readers can also make linear combinations of results from different simulations. For example, the effects of a 10 per cent tax-induced reduction in beef consumption combined with a 0.39 per cent increase in labor supply can be well approximated by adding the results from simulations 1 and 5.

Table 2. 1. Reduction in U.S. consumption of beef, cuts in health expenditures and increases in labor supply: macro effects in 2020 of policies implemented in 2015 (deviations from baseline)

		10% reduction in consumption of beef through a:			3.32% cut in health service requirements (Sim 4)	0.39% increase in labor supply (Sim 5)
		Beef tax (Sim 1)	Preference shift to all other food (Sim 2)	Preference shift to veggie burger (Sim 3)		
	Percentage changes					
1	Real GDP (Y)	-0.003	0.003	0.000	0.121	0.374
2	Real private consumption (C)	-0.006	0.003	-0.003	0.088 (0.784)[a]	0.359
3	Real investment (I)	0.021	0.004	-0.002	0.277	0.358
4	Real public consumption (G)	-0.006	0.003	-0.003	0.088	0.362
5	Real exports (X)	-0.010	0.015	0.086	0.337	0.352
6	Real imports (M)	0.005	0.011	0.047	0.309	0.257
7	Aggregate employment (L)	0.000	0.000	0.000	0.000	0.390
8	Aggregate capital (K)	0.030	0.011	0.002	0.293	0.360
9	Real wage (W/P_c)	-0.022	0.001	-0.011	-0.065	0.060
10	Exchange rate (+ = appreciation)	-0.001	-0.006	-0.043	-0.120	-0.231
11	Price deflator for C (P_c)	0.000	0.000	0.000	0.000	0.000
12	Terms of trade	0.010	-0.005	-0.029	-0.109	-0.112
13	Consumption of food	-1.280	0.002	0.015	0.367	0.193
	Percentage point changes					
14	Trade balance, % of GDP	-0.001	-0.001	-0.002	-0.024	-0.007
15	Net f'gn liabilities, % of GDP	0.001	0.000	0.000	0.008	0.007

(b) This is the percentage increase in real consumption excluding health expenditure.

Table 2.2. Reduction in U.S. consumption of beef, cts in health expenditures and increases in labor supply: industry/sector output effects in 2020 of policies implemented in 2015 (% deviations from baseline)

		10% reduction in consumption of beef through a:			3.32% cut in health service requirements (Sim 4)	0.39% increase in labor supply (Sim 5)
		Beef tax (Sim 1)	Preference shift to all other food (Sim 2)	Preference shift to veggie burger (Sim 3)		
1	Agriculture	-1.197	-0.769	-0.873	0.370	0.317
2	OilSeedFarm	0.073	0.219	0.500	0.273	0.264
3	GrainFarm	-0.278	0.074	-0.066	0.377	0.334
4	VegMelonFarm	0.332	1.183	3.784	0.377	0.308
5	FruitNutFarm	0.164	0.516	1.461	0.292	0.259
6	GreenNursPrd	0.030	0.034	0.019	0.443	0.339
7	OthCropFarm	-0.171	0.103	-0.252	0.368	0.336
8	CattRancFarm	-6.808	-6.761	-6.875	0.340	0.311
9	DairCattProd	0.686	1.783	0.080	0.391	0.301
10	OtherAnimal	-4.455	-4.419	-4.567	0.440	0.386
11	PoultryEgg	0.386	1.414	0.878	0.401	0.269
12	ForestLog	0.043	0.024	0.057	0.385	0.435
13	FishHuntTrap	0.162	0.496	1.830	0.396	0.370
14	AggSupportServ	-0.467	-0.121	-0.074	0.356	0.335
15	Mining	0.020	0.007	0.022	0.268	0.278
16	Utilities	0.066	0.013	0.008	0.558	0.378
17	Construction	0.048	0.007	0.001	0.360	0.364
18	ManuOther	0.030	0.017	0.043	0.366	0.401
19	FoodManu	-1.032	-0.236	-0.864	0.395	0.297
20	FlourMaltMill	0.361	1.238	1.672	0.437	0.314
21	WetCornMill	0.318	0.777	1.511	0.416	0.361
22	SoyOilProc	0.146	0.648	1.495	0.403	0.327
23	FatsOils	0.345	1.284	2.855	0.403	0.275
24	BreakCereal	0.426	1.526	5.214	0.414	0.280
25	SugarConfect	0.442	1.507	0.195	0.469	0.325
26	FrozFood	0.499	1.684	0.110	0.431	0.281
27	FrtVegCanning	0.564	1.667	6.221	0.377	0.305
28	MilkButter	0.657	1.881	0.051	0.377	0.269

…Table 2.2 continues

Table 2.2 continued …

		10% reduction in consumption of beef through a:			3.32% cut in health service requirements (Sim 4)	0.39% increase in labor supply (Sim 5)
		Beef tax (Sim 1)	Preference shift to all other food (Sim 2)	Preference shift to veggie burger (Sim 3)		
29	Cheese	0.796	1.898	0.039	0.421	0.327
30	DryCondEvapDairy	0.546	1.480	0.064	0.392	0.314
31	IceCream	1.174	2.404	0.003	0.033	0.328
32	AnimalProc (beef)	-7.555	-7.548	-7.565	0.325	0.299
33	PoultryProc	0.389	1.443	-0.232	0.404	0.275
34	Seafood	1.211	2.425	0.046	0.081	0.334
35	BreadBakery	0.536	1.701	0.005	0.444	0.280
36	CookiePasta	0.495	1.710	0.026	0.420	0.256
37	SnackFood	0.430	1.514	0.011	0.426	0.261
38	CoffTea	0.738	1.880	0.343	0.195	0.270
39	FlavorSyrup	0.473	0.977	0.991	0.587	0.415
40	SeasoningDressing	0.431	1.549	0.494	0.388	0.279
41	OthrFoodManu	0.424	1.464	0.233	0.420	0.281
42	SoftDrinks[(a)]	0.041	0.009	0.009	0.548	0.331
43	OtherServices	0.014	0.013	0.016	0.426	0.377
44	Health	0.078	0.003	0.004	-2.952	0.399
45	FoodServingSpecialists[(b)]	-0.082	0.006	0.010	0.801	0.397
46	AccHotels	0.044	0.005	0.007	0.754	0.395
47	FullRestaur	-0.130	0.007	0.013	0.762	0.397
48	LimRestaur	-0.090	0.005	0.009	0.851	0.399

(b) We classified Soft drink as part of Food manufacture. However, Soft drink was not included among the commodities for which there was a favorable preference shift in any of simulations 1 to 3.

(c) This is a subset of the Food serving industries listed in the right panel of Table 1.1.

Table 2.3. Reduction in U.S. consumption of beef, cuts in health expenditures and increases in labor supply: industry/sector employment effects in 2020 of policies implemented in 2015 (% deviations from baseline)

		10% reduction in consumption of beef through a:			3.32% cut in health service requirements (Sim 4)	0.39% increase in labor supply (Sim 5)
		Beef tax (Sim 1)	Preference shift to all other food (Sim 2)	Preference shift to veggie burger (Sim 3)		
1	Agriculture	-1.556	-1.088	-1.027	0.426	0.349
2	OilSeedFarm	0.100	0.322	0.753	0.383	0.347
3	GrainFarm	-0.347	0.086	-0.074	0.454	0.382
4	VegMelonFarm	0.394	1.421	4.572	0.435	0.338
5	FruitNutFarm	0.215	0.692	1.969	0.380	0.324
6	GreenNursPrd	0.028	0.036	0.024	0.476	0.347
7	OthCropFarm	-0.210	0.120	-0.294	0.431	0.375
8	CattRancFarm	-7.600	-7.542	-7.672	0.376	0.331
9	DairCattProd	0.721	1.905	0.078	0.417	0.309
10	OtherAnimal	-5.001	-4.959	-5.120	0.476	0.402
11	PoultryEgg	0.449	1.684	1.043	0.471	0.298
12	ForestLog	0.055	0.030	0.075	0.421	0.462
13	FishHuntTrap	0.186	0.559	2.072	0.440	0.395
14	AggSupportServ	-0.494	-0.114	-0.047	0.386	0.350
15	Mining	0.030	0.009	0.039	0.384	0.383
16	Utilities	0.079	0.015	0.017	0.660	0.408
17	Construction	0.054	0.007	0.005	0.385	0.378
18	ManuOther	0.037	0.018	0.055	0.360	0.428
19	FoodManu	-0.990	-0.128	-0.802	0.424	0.309
20	FlourMaltMill	0.375	1.325	1.673	0.468	0.326
21	WetCornMill	0.312	0.752	1.484	0.431	0.386
22	SoyOilProc	0.169	0.723	1.646	0.435	0.346
23	FatsOils	0.321	1.293	2.874	0.443	0.301
24	BreakCereal	0.474	1.677	5.247	0.450	0.293
25	SugarConfect	0.475	1.623	0.194	0.505	0.341
26	FrozFood	0.519	1.769	0.173	0.456	0.291
27	FrtVegCanning	0.600	1.755	6.365	0.403	0.318
28	…MilkButter	0.679	1.931	0.118	0.395	0.282

Table 2.3 continues

Table 2.3 continued …'

		10% reduction in consumption of beef through a:			3.32% cut in health service requirements (Sim 4)	0.39% increase in labor supply (Sim 5)
		Beef tax (Sim 1)	Preference shift to all other food (Sim 2)	Preference shift to veggie burger (Sim 3)		
29	Cheese	0.826	1.994	0.044	0.446	0.338
30	DryCondEvapDairy	0.581	1.583	0.084	0.410	0.324
31	IceCream	1.245	2.564	0.022	0.047	0.342
32	AnimalProc (beef)	-7.975	-7.953	-7.980	0.346	0.310
33	PoultryProc	0.377	1.501	-0.263	0.430	0.285
34	Seafood	1.250	2.522	0.021	0.098	0.351
35	BreadBakery	0.608	1.908	0.009	0.457	0.282
36	CookiePasta	0.532	1.830	0.003	0.452	0.267
37	SnackFood	0.463	1.624	0.033	0.462	0.273
38	CoffTea	0.769	1.967	0.383	0.223	0.289
39	FlavorSyrup	0.539	1.138	1.097	0.633	0.438
40	SeasoningDressing	0.506	1.685	0.676	0.418	0.294
41	OthrFoodManu	0.326	1.399	0.153	0.444	0.293
42	SoftDrinks[(a)]	0.056	0.037	0.044	0.579	0.347
43	OtherServices	0.021	0.017	0.022	0.313	0.383
44	Health	0.106	0.003	0.005	-3.117	0.409
45	FoodServingSpecialists[(b)]	-0.030	0.005	0.011	0.857	0.409
46	AccHotels	0.075	0.003	0.007	0.901	0.413
47	FullRestaur	-0.053	0.006	0.013	0.788	0.405
48	LimRestaur	-0.054	0.005	0.011	0.909	0.411

(a) We classified Soft drink as part of Food manufacture. However, Soft drink was not included among the commodities for which there was a favorable preference shift in any of simulations 1 to 3.

(b) This is a subset of the Food serving industries listed in the right panel of Table 1.1.

2.1 Macro results, Table 2.1

2.1(a) Simulations 1 to 3: reducing beef consumption by 10 per cent

Simulations 1 to 3 each show the effects of a 10 per cent reduction in beef consumption both at home and in restaurants and other food-serving venues. In simulation 1, the 10 per cent reduction is generated by taxes of about 34 per cent imposed on direct purchases of beef by households and on beef purchases by food-serving organizations. The revenue from the tax is returned to households via general reductions in taxes on all household purchases (food and non-food). In net terms the taxes have no direct effect on household disposable income. In simulations 2 and 3, the 10 per cent reduction is generated by preference shifts against beef and towards other food products. The two simulations differ with respect to the set of beef-replacing other food products. In simulation 2 there is a uniform shift towards all other food products with no overall change in preferences between food products and non-food products. In simulation 3 we continue to assume no overall change in preferences between food-products and non-food products, but within the food group we assume that the shift in from beef to food commodities that are prominent in the manufacture of non-meat substitutes (veggie burgers) such as vegetables and cereals (see Table 1.1, footnote 2). In simulations 1 to 3 there are no flow-on effects to health expenditures and labor-force participation.

Table 2.1 shows that the macro effects of simply replacing beef with other products are very small. For example, the GDP effect varies across the three simulations from -0.003 per cent to +0.003 per cent. Nevertheless, we provide explanations, if for no other reason than to check that our computations are done correctly and to identify determining mechanisms and assumptions.

We start with food consumption in row 13 of Table 2.1. This is the only variable in the table for which there is significant variation across the first three simulations, -1.280 per cent in simulation 1 and close to zero in simulations 2 and 3. The beef tax in simulation 1 makes food expensive relative to non-food products. While the tax induces substitution from beef to other food products, it also induces substitution from food in general to non-food.[3] This general substitution effect against food is quantitatively negligible in simulations 2 and 3. In those simulations, there is no tendency for food to become expensive relative to non-food. It is the food/non-food substitution effect that explains simulation 1's relatively large negative outcome for food consumption.

As we will see in Table 2.3, the three beef-reduction policies cause employment to increase in some industries and to decline in others. Similarly, they cause capital stocks to increase in some industries and decline in others. However, we assume that the policies under consideration, implemented in 2015, have no effect on aggregate employment in 2020: wage rates adjust to ensure that aggregate employment in 2020 is on its baseline path. For capital, we assume that the policies under consideration have no effect on the average rate of return to capital in 2020 across the economy. Industries that are favored by the shocks gain capital, driving their rates of return in 2020 back towards baseline levels while industries that are harmed by the shocks lose capital allowing their rates of return to recover towards baseline levels. In our policy runs, this process at the industry level is not complete, leaving rates of return in 2020 in gaining industries a little above their baseline levels and rates of return in losing industries a little below their baseline levels.

[3] In USAGE-Food, food products are nested in the industry production functions and household utility function, see Appendix 3. This nesting allows price-induced substitution between individual food products and between food in general and individual non-food products.

Consistent with our assumption on aggregate employment, row 7 in Table 2.1 for simulations 1 to 3 shows zero effects. With no change in average rates of return, as a first approximation we would expect no change in the economy-wide capital to labor ratio. Thus, we would expect to see numbers close to zero in the aggregate capital row (row 8) for simulations 1 to 3. The small positive numbers in row 8 reflect policy-induced changes in industrial composition. The beef industries (Beef processing and Cattle ranching) are relatively labor and land intensive. Their contraction in favor of other activities increases the capital intensity of the economy.[4] This effect is most pronounced in simulation 1 because food production (which contracts in simulation 1) has relatively low capital intensity. The capital effect is more pronounced in simulation 2 than in simulation 3 because within the food nest production of food in general is more capital intensive than production of the inputs we have assumed for "veggie burgers".

With zero change in aggregate labor input and a 0.030 per cent increase in aggregate capital input, our first guess is that GDP in simulation 1 should increase by about 0.010 per cent (returns to capital account for about a third of GDP). However, there is a small negative result. This is caused by an efficiency effect, familiar to economists as a welfare triangle. As illustrated in Figure 2.1, the beef tax generates an efficiency loss for the economy of about 0.013 per cent of GDP by forcing households to cut their consumption of a product (beef) on which they place a higher value (the tax-inclusive price) than the cost to the economy of producing it (the tax-exclusive price). This negative welfare triangle, together with the capital contribution, explains simulation 1's GDP result of -0.003 per cent (= 0.010 – 0.013). The triangle is not present in simulations 2 and 3. Consequently, those simulations give GDP results that are broadly consistent with their capital and labor results.

Looking at rows 5 and 6 of Table 2.1, we see quite different results for trade variables. When beef consumption is reduced by 10 per cent through a preference shift towards veggie burgers (simulation 3) trade volumes are stimulated (0.086 per cent for exports and 0.047 per cent for imports). If the preference shift is towards food in general (simulation 2), then trade is also stimulated by but by much smaller percentages than in simulation 3. When a tax is used to achieve the 10 per cent reduction in the consumption of beef, exports contract and there is barely any increase in imports.

These contrasting trade results are explained mainly by what happens in the three simulations to the commodity composition of household consumption. In simulation 3, the composition of consumption changes towards commodities for which the U.S. has a relatively high dependence on imports.[5] In simulation 2, this effect is present but much weaker than in simulation 3, and in simulation 1 it is weaker still. In simulation 3 the shift out of beef, which has low import-intensity, is towards vegetables, fruit and fish that have high import-intensity. In simulation 2, the switch out of beef is towards food in general, which although having higher average import-intensity than beef, has lower import-intensity than the veggie burger commodities. In simulation 1, the switch out of beef is towards food in general but also towards non-food commodities. These non-food commodities have lower import-intensity than food commodities.

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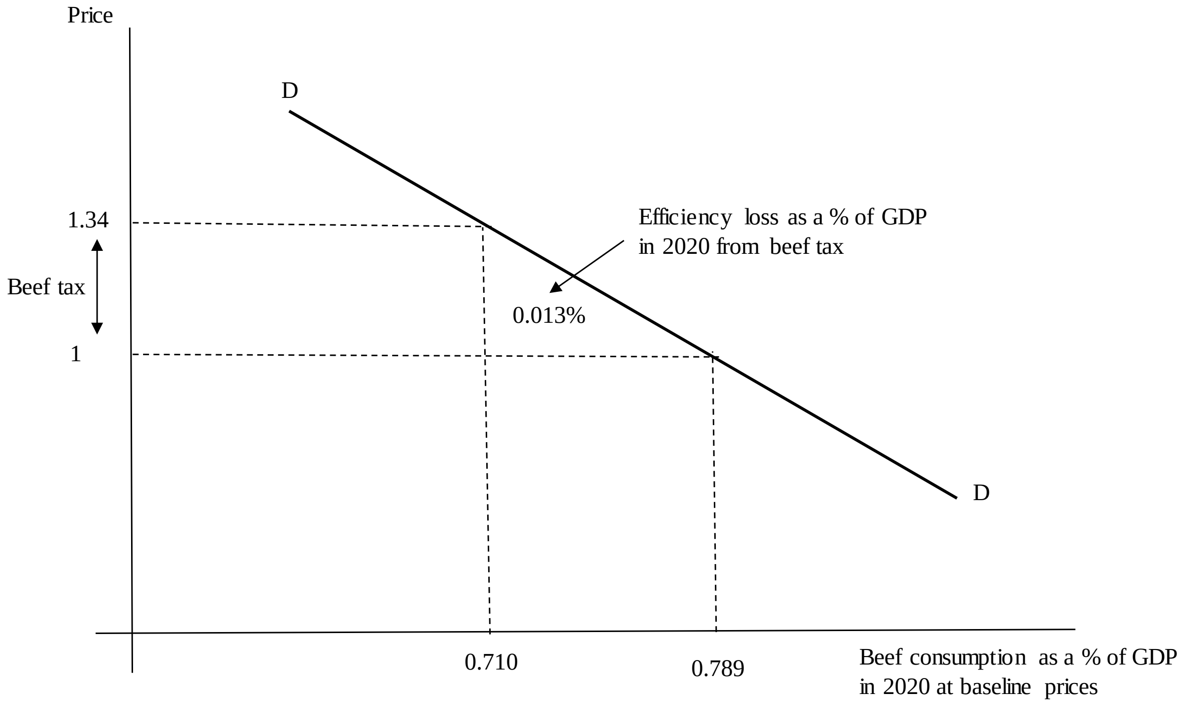
[4] We measured the impact of policies on capital intensity by making a weighted average of the percentage deviations in industry outputs using returns to capital as weights.

[5] For each simulation, we measured the impact effect on imports of the policy-induced changes in the composition of consumption by making a weighted average of the percentage deviations in consumption by commodity using household purchases of imports as weights.

Figure 2.1. Demand for beef and efficiency loss from beef tax



DD is a stylized representation of household demand in USAGE-Food for beef in 2020, either through direct purchases or through food-serving organizations such as restaurants. In the baseline, household beef consumption (valued at basic prices) accounts for 0.789 per cent of GDP. Simulation 1 implies that a tax of about 34 per cent reduces the *quantity* of consumption by 10 per cent. In the figure, this is expressed as a reduction in beef consumption from 0.789 per cent of baseline GDP to 0.710 per cent of baseline GDP. In calculating the 0.710 per cent, we use the baseline price for beef.

Stimulation of imports normally stimulates exports: imports need to be paid for by exports. Exchange rate adjustments are the underlying mechanism. On this basis, we can understand why trade is stimulated in simulation 3 relative to simulation 2 relative to simulation 1.

The trade-flow results in Table 2.1 for simulations 1 to 3 reflect not only what is happening to the composition of household consumption, but also what is happening to investment. Consistent with increased economy-wide capital intensity, simulation 1 shows a relatively large increase in the investment to GDP ratio (a 0.021% deviation for investment compared with a -0.003% deviation for GDP). With public and private consumption modeled as moving approximately in line with GDP, an increase in I/GDP tends to produce a deterioration in the trade balance and an increase in net foreign liabilities (rows 14 and 15). The deterioration in the trade balance is normally split between a reduction in exports and an increase in imports. In simulation 1, the investment-related effects on exports and imports produce the negative result in row 5 and the positive result in row 6. With only small deviations in investment in simulations 2 and 3, the effects, already explained, from changes in the import-intensity of consumption are the dominant determinants of the trade-flow results.

Stimulation of exports in simulations 2 and 3 is accompanied by deterioration in the terms of trade (the foreign-currency price of exports relative to that of imports, row 12). Selling more exports requires a reduction in their price. Terms-of-trade deterioration explains how simulations 2 and 3 give negative results for the trade balance (row 14) despite showing larger percentage increases in export volumes than import volumes.[6] Similarly, retardation of exports in simulation 1 is accompanied by an improvement in the terms of trade.

The final macro results that we will consider for simulations 1 to 3 are those for real wage rates (row 9 in Table 2.1). Under our assumption that the economy-wide average rate of return on capital in 2020 is unaffected by beef-reduction policies, returns to labor (real wage rates) bear all the burden of efficiency and terms of trade losses. In simulation 1, the efficiency loss, worth 0.013 per cent of GDP, translates into a reduction in real wage rates of about 0.20 per cent (= 0.013/0.65, returns to labor are about 65 per cent of GDP). This explains most of the real wage loss of 0.022 per cent. In simulation 2, there is neither an efficiency loss nor a significant terms of trade change. Consequently, the real wage deviation in this simulation is close to zero. In simulation 3, there is no efficiency loss but there is a sizable terms-of-trade decline which has a noticeable negative effect on real wage rates (-0.011 per cent).

2.1(b) Simulation 4: cutting health expenditures

Simulation 4 gives the effects of a reduction in required health expenditures by both the private and public sectors. This enables both sectors to expand their consumption of other goods and services. The macroeconomic effects in Table 2.1 of this switch from health expenditures to non-health expenditures depends on three features of health expenditures. First, production of health services is highly labor intensive (a labor share in returns to primary factors of 80 per cent, compared with about 60 per cent for the rest of the economy). Second, imports of health services are negligible. Third, expenditures on health services are lightly taxed relative to expenditures on other commodities. Thus, cutting back on production and consumption of health services in favor of other commodities: (1) increases the capital intensity of the economy, row8 of Table 2.1; (2) stimulates imports and thereby stimulates exports, rows 5 and 6; and (3) produces an efficiency gain. The efficiency gain arises from stimulation of consumption of commodities in which there is a relatively large gap between value to consumers (tax-inclusive price) and cost to the economy (tax-exclusive price), and retardation of consumption of health services in which this gap is small. The efficiency gain explains why the GDP increase of 0.121 per cent is more than could be expected on the basis of the contribution from the increase in capital (about a third of 0.293 per cent).

The increases in private and public consumption (0.088 per cent, rows 2 and 4) are subdued relative to that in GDP. The increase in capital is the major contributor to the increase in GDP, but it makes a relatively minor contribution to the increases in private and public consumption. The switch in expenditures away from health does not change savings rates in the U.S., implying that extra capital is financed by foreigners. Thus, much of the gain in GDP associated with the increase in capital accrues to foreigners and is not available to stimulate consumption. Gross national product (GNP, which is GDP less net income accruing to foreigners) on which consumption depends is increased by extra capital in simulation 4 only to the extent to which extra capital generates extra taxes paid by foreigners.

Consistent with the increase in capital intensity, simulation 4 produces an increase in investment relative to GDP (0.277 per cent in row 3, relative to 0.121 per cent). This

[6] Another factor in the calculation of trade-balance effects is the baseline trade balance. For 2020 this is strongly negative. Consequently, percentage changes in export prices and volumes operate on a smaller base than percentage changes in import prices and volumes.

generates a deterioration in the trade balance and an increase in net-foreign liabilities (rows 14 and 15).

Stimulation of exports in simulation 4 produces a terms-of-trade decline (row 13). This inhibits consumption growth. However, the consumption effects are still positive (0.088 per cent). The negative terms-of-trade effect is outweighed by the combined effects of the efficiency gain and the taxes on extra foreign-owned capital in the U.S.

The most important macro result in simulation 4 is the 0.784 per cent increase in real private consumption excluding health. This is an indicator of the welfare gain to U.S. households from the assumed 3.32 percent reduction in health-service requirements. With reduced necessity for health expenditures, U.S. households are able to improve their welfare by increasing their consumption of utility-giving commodities.

Why 0.784 per cent? Health expenditures represent about 16.6 per cent of private consumption. Thus, a 3.32 per cent reduction in health requirements is a saving worth 0.551 per cent of consumption. Together with the overall increase in consumption of 0.088 per cent, the reduction in health requirements gives households extra spending power on non-health commodities of 0.639 per cent of aggregate household consumption. This suggests an increase of 0.766 per cent [= 0.639/(1-0.166)] in the consumption of non-health commodities, close to the simulated result.

While the increase in household consumption averaged across non-health commodities is 0.784 per cent, the increase in food consumption (row 13) is only 0.367 per cent. Expenditure elasticities of demand for food commodities are relatively low.

2.1(c) Simulation 5: increasing labor supply

Under the assumptions of zero deviation in the economy-wide rate of return on capital and constant-returns-to-scale production functions in each industry, CGE models such as USAGE-Food imply that a 0.390 per cent increase in labor supply (and employment) will produce an increase in aggregate capital of approximately 0.390 per cent. This is because under these assumptions, the K/L ratio must be approximately constant.

As can be seen from the results for simulation 5 in Table 2.1, the increase in capital stock (row 8) is only 0.360 per cent. Why does the K/L ratio fall? While there are constant returns to scale in production functions at the industry level, there are diminishing returns to expansion of the economy as a whole. Diminishing returns arise from two factors: fixed agricultural land and the limited size of foreign markets for U.S. products (the U.S. expands in simulation 5 but the rest of the world doesn't). In the presence of these two factors and in the absence of technology improvements, expansion of the economy causes increases in rental rates on agricultural land and reductions in the prices of U.S. products on world markets (terms-of-trade decline, row 12). With the economy-wide rate of return on capital being held constant, wage rates must bear the cost of both the increased rentals on land and lower international prices for U.S. products. Thus, the cost to producers of using labor falls relative to the cost of using capital. This induces substitution in favor of labor, causing a decline in the K/L ratio as L rises.

In view of the argument in the previous paragraph, it may seem surprising that simulation 5 shows an increase in the real wage rate (0.060 per cent, row 9). An increase in labor force participation generates extra tax revenues for the government and reduces social security payments. In our simulation, these two budgetary benefits are returned to households via reductions in indirect taxes applying to consumer spending. This allows real wages from the point of view of workers (wage rates deflated by consumer prices, as in row 9) to rise even when there is a decline in real wage rates from the point of view of employers (wage rates deflated by a combination of labor and capital costs).

With the percentage expansion in capital (0.360 per cent) being less than that in labor, the percentage increase in GDP (0.374 per cent) is also less than that in labor.

Although the percentage increase in capital in simulation 5 is greater than in simulation 4 (0.360 per cent compared with 0.293 per cent), the build up in net foreign liabilities in simulation 5 is less than that in simulation 4 (0.007 per cent of GDP compared with 0.008 per cent). Unlike simulation 4, in simulation 5 the increase in GNP is similar to that in GDP. Most of the increase in GDP in simulation 5 is generated by a domestically owned factor of production, labor. Thus in simulation 5, there is an increase in domestic saving that finances much of the increase in capital. Also, with GNP increasing in line with GDP, private and public consumption increase by approximately the same percentage as GDP (compare rows 2 and 4 with row 1).

As in simulation 4, a negative terms-of-trade effect in simulation 5 leaves the balance of trade moving towards deficit (row 14) despite an increase in the volume of exports relative to the volume of imports (rows 5 and 6).

Finally, on the macro results for simulation 5, we note that the consumption of food (row 13) is subdued (an increase of 0.193 per cent compared with the increase in total consumption of 0.359 per cent). As in simulation 4, this reflects low expenditure elasticities of demand for food commodities.

2.2 Industry output results, Table 2.2

2.2(a) Simulations 1 to 3: reducing beef consumption by 10 per cent

In simulations 2 and 3 there is barely any change in U.S. food consumption (row 13, Table 2.1). Nevertheless, these simulations show negative results for Agricultural output (-0.769 and -0.873 per cent, row 1, Table 2.2). As explained in subsection 2.1(a), the shift in food consumption against beef increases the import-intensity of food purchases. This reduces the share of food purchases accounted by domestic production with consequent reductions in agricultural output. The shift toward import-intensive ways of satisfying food requirements is particularly pronounced in simulation 3 in which there is strong stimulation in demand for import-intensive products (the veggie-burger commodities) such as Vegetables, Fruit & nuts and Fish (see rows 4, 5, and 13 in Table 2.2). Consequently, simulation 3 shows more damage to Agricultural output than simulation 2. In simulation 1, the change in the composition of food consumption is approximately the same as that in simulation 2. However, there is an extra negative influence acting on Agriculture in simulation 1 that is not present in the other two simulations, namely the tax-induced reduction in food consumption relative to non-food, explained in subsection 2.1(a). This leaves Agriculture with a more negative result (-1.197 per cent) in simulation 1 than in simulations 2 and 3.

Within the Agricultural sector, the commodities with the largest percentage reductions in output in simulations 1 to 3 are Cattle ranching (row 8) and Other animals (row 10), e.g. pigs & sheep. These commodities are supplied to Animal processing (row 32) whose principal output is beef products. In simulations 1 to 3, the assumed reduction in beef consumption is represented as a 10 per cent reduction in demand for Animal processing. With the same demand reduction in the three simulations, it is not surprising that the output results for Animal processing are approximately the same across the simulations, about -7.6 per cent (row 32). Why not -10 per cent? The main reason is that Animal processing has non-food sales (e.g. pet supplies) and some exports, neither of which is affected by the 10 per cent reduction in household consumption of Animal processing. Another factor is that the reduction in demand for Animal processing flows on to a reduced demand for Cattle ranching and Other animals, reducing their prices. This leads to a reduction in the input costs to the Animal processing industry, which gives the industry a competitive advantage against imports and boosts exports. With output of Animal processing reduced by approximately the same percentage, 7.6 per cent, in simulations 1 to 3, there is little variation across the simulations in the output reductions in Cattle ranching (about -6.8 per cent, row 8) and Other animals (about -4.5 per cent, row 10). Why aren't the reductions closer to 7.6 per cent? Both Cattle ranching and Other animals are sold outside Animal processing and both get minor boosts from improved competitiveness in their export markets and against imports in their domestic markets.

In simulation 2, all of the food-producing agricultural[7] and manufacturing industries apart from Cattle ranching, Other animals and Animal processing experience an increase in output from the switch away from beef to food products in general. In simulation 3, the output increases for most of the veggie burger commodities are considerably greater than in simulation 2 (rows 4, 5, 13, 20-24, and 27). Correspondingly, the output results for most non-veggie burger food-producing agricultural and manufacturing industries are weaker in simulation 3 than in simulation 2. Exceptions to these generalizations include Poultry & egg (row 11) which is a veggie burger commodity but does better in simulation 2 than in simulation 3, and Oil seed farm which is not a veggie burger commodity but does better in simulation 3 than in simulation 2. Poultry & egg is harmed in simulation 3 through a decline in its sales to Poultry processing (row 33) which is not a veggie burger commodity. Oil seed farm benefits in simulation 3 from stimulation of its sales to Soy oil processing (row 22) and Fats & oils (row 23), both of which are veggie burger commodities.

U.S. output of both Agriculture and Food manufacturing (rows 1 and 19) fall as we move from simulation 2 to simulation 3. As explained already, Agricultural output is reduced in simulation 3 relative to 2 by the shift in preferences in 3 towards commodities that are heavily imported. But why is the overall output of Food manufacturing lower in simulation 3 than in simulation 2? The answer is that the preference shift towards veggie-burger commodities in simulation 3 switches demand from food commodities that are produced by manufacturing processes towards food commodities that are supplied directly by agriculture.

With two exceptions, the Agricultural and Food-manufacturing industries have weaker output responses in simulation 1 than in simulation 2. This reflects the tax-induced shift in simulation 1 away from food commodities to non-food commodities. The two exceptions are Forestry & logging (row 12) and Soft Drinks (row 42). While we classify Forestry & logging as part of Agriculture, it is not a food producing industry, and while we classify Soft drinks as part of Food manufacturing, it is not one of the commodities in the nest of food substitutes in simulations 1 and 2.

Outside Agriculture and Food manufacturing, the industry and sectoral effects in simulations 1 to 3 are small. Here we comment on just a few cases in which there is notable variation across simulations 1 to 3. Health (row 44) and Utilities (row 16) are stimulated in simulation 1 relative to simulations 2 and 3 because of the tax-induced diversion in simulation 1 of consumer spending away from food into non-food. Restaurants (rows 47 and 48) decline in simulation 1 relative to 2 and 3 because the beef tax in simulation 1 makes restaurant meals expensive. Accommodation & hotels (row 46) has less dependence on inputs of beef

[7] These is a reduction in the output of Agricultural support services (row 14). The reduction in demand for these services from Cattle ranching and Other animals outweighs the increase in demand from other agricultural industries.

products than is the case for restaurants. The negative effect on Accommodation & hotels of the beef tax is outweighed in simulation 1 by the positive effect of the tax-induced shift from food to non-food. Construction (row 17) does better in simulation 1 than in simulations 2 and 3 because investment does better in simulation 1.

2.2(b) Simulation 4: cutting health expenditures

The standout result for simulation 4 in Table 2.2 is for Health (row 44), a reduction in output of 2.952 per cent. Why not 3.32 per cent, the imposed reduction in household demands for health services? The reason is that we applied the 3.32 per cent to only about 90 per cent of health services produced in the U.S. We exempted health services supplied to: U.S. residents on vacation in the U.S.; sports organizations; and foreigners (either direct exports or health services to foreign visitors).

Most of the other industry and sector output results for simulation 4 in Table 2.2 are in the range 0.25 per cent to 0.55 per cent, centred on 0.40 per cent. Why 0.40 per cent? As mentioned in subsection 2.1(b), the saving of health expenditures is worth 0.551 per cent of baseline private consumption, or about 0.4 per cent of GDP. Thus, on average, industries outside the health sector expand output by about 0.4 per cent.

Considerably larger output expansions are shown for non-health industries whose sales share to households is large (say 50 per cent or more) and for which the household expenditure elasticity of demand is high (greater than 0.75). Commodities fitting this description include Utilities (row 16), Accommodation & hotels (row 46), Restaurants (rows 47 and 48) and Soft drinks (row 42). Industries producing these commodities benefit from the 0.784 per cent increase in consumption of non-health commodities made possible by the 3.32 per cent health saving. While not having significant direct sales to households, Flavor Syrups (row 39) also appears in Table 2.2 with an elevated output result (0.587). This commodity is sold to Soft drinks and Restaurants. Non-health commodities shown in Table 2.2 with subdued stimulation in simulation 4 include Icecream (row31), Seafood (row 34) and Coffee & tea (row 38). All of these commodities have low expenditure elasticities, limiting the boost that they receive from increased spending power by households. At the same time, all of them have a major share of their sales to industries that we classified in the health group, including, Hospitals and Nursing homes.

2.2(c) Simulation 5: increasing labor supply

Unlike simulations 1 to 4 in which we introduced cuts in beef consumption and health requirements, in simulation 5 there is no direct shock to the commodity composition of demand. The increase in labor supply and employment of 0.39 per cent assumed in simulation 5 produces output stimulation across all commodities in a relatively narrow range, averaging 0.374 per cent (GDP result in Table 2.1). In Table 2.2 the largest output deviation in simulation 5 is 0.435 per cent for Forestry & logging (row 12) and the smallest is 0.256 for Cookies & pasta (row 36). Variations within this range depend mainly on two factors: expenditure elasticity; and import competition.

Figure 2.2. Regression relationship between industry employment and output responses in simulation 1

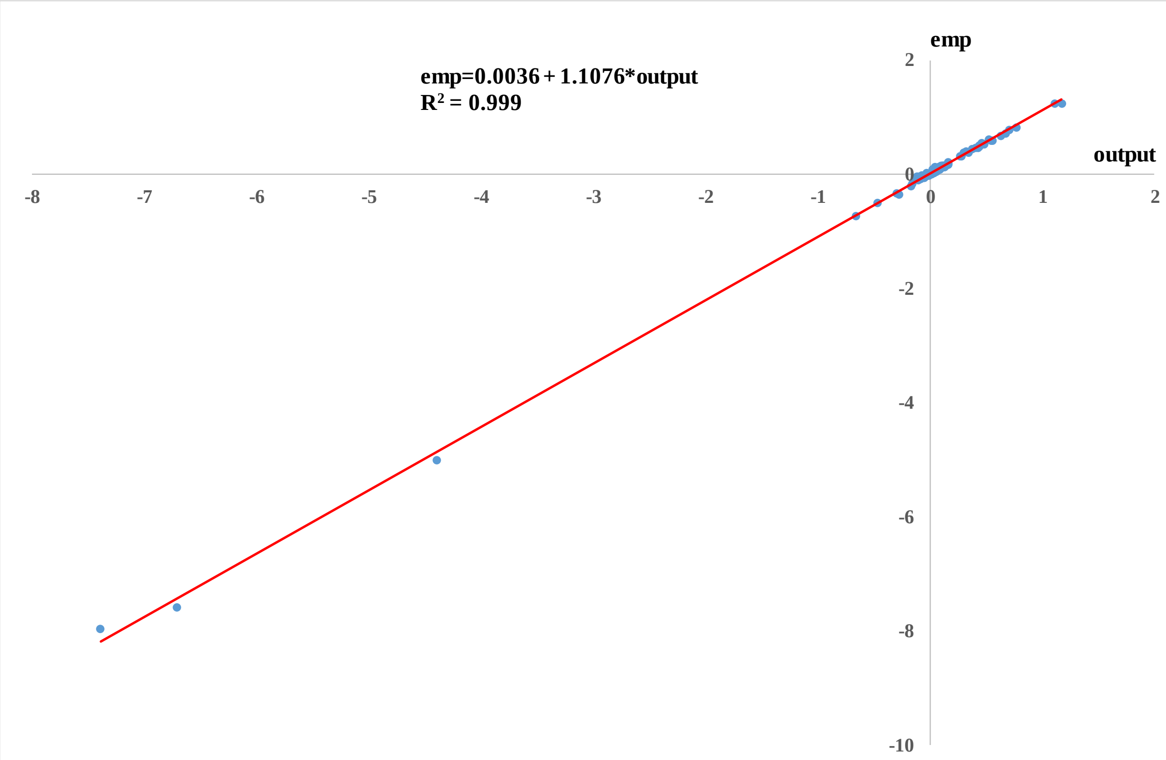


Table 2.4. Relationships between employment and output deviations in simulations 1 to 5

	α	β	R^2
Sim 1: beef tax	0.0036 (0.001)	1.1075 (0.002)	0.999
Sim 2: preference shift to all other food	-0.0012 (0.001)	1.1055 (0.002)	0.999
Sim 3: preference shift to veggie burger	0.0044 (0.002)	1.1181 (0.003)	0.998
Sim 4: 3.32% cut in health service requirements	0.0009 (0.002)	1.0763 (0.003)	0.998
Sim 5: 0.39% increase in labor supply	0.0136 (0.004)	1.0109 (0.011)	0.957

Standard errors in parentheses

With population held constant, an increase in employment generates an increase in per capita income. Expenditure elasticities are relatively low for most food items including Cookies & pata). Thus, the output response to increases in per capita income for these items in simulation 5 is generally below average. By contrast, expenditure elasticities for Food serving specialists (rows 46 to 48) are high, giving these commodities above average output responses. Two other commodities showing noticeably above-average output responses in simulation 5 are Forestry & logging (row 12) and Flavors & syrups (row 39). Both these commodities face strong import competition. Because of adverse terms-of-trade effects, expansion of labor supply in simulation 5 is accompanied by devaluation. This improves the competitiveness of import-competing commodities, boosting their output.

2.3 Industry employment results, Table 2.3

Our description of these results can be brief. The employment results in Table 2.3 are closely related to the output results in Table 2.2 that we have already described. The relationships between the two sets of results can be quantified by regression equations of the form

$$emp_k(i) = \alpha_k(i) + \beta_k(i) * output_k(i) \quad , \; i = 1, 2, \ldots , 387 \text{ and } k = 1, \ldots, 5$$

where

$emp_k(i)$ and $output_k(i)$ are percentage deviations in employment and output for industry i in simulation k; and

$\alpha_k(i)$ and $\beta_k(i)$ are regression coefficients.

As set out in Appendix 2, USAGE-Food has 392 industries. However, five of these have zero employment: they are artificial industries such as export tourism which produce services consisting of an amalgam of intermediate inputs with no direct use of primary factors. These five industries are omitted from our regression equations.

Figure 2.2 illustrates the regression for simulation 1. Regression results for all five simulations are set out in Table 2.4. In all cases the fit is nearly perfect, supporting the idea that once we have explained the output results, the employment results follow mechanically.

The β coefficients in Table 2.4 are all above 1. As explained in subsection 2.1(a), rates of return on capital in industries that are relatively favored by the shock under consideration are elevated in 2020 while rates of return in industries that are relatively harmed are reduced. This means that in industries that expand relative to average there is substitution of labor for capital (capital is scarce). Thus, in industries where output expands relative to average the labor/capital ratio rises, implying that the labor/output ratio rises. Similarly, in industries where output contracts relative to average the labor/capital ratio falls, implying that the labor/output ratio falls. These movements in labor/output ratio explain why β is greater than one.

The R^2 for regression equation 5 is lower than that for the other equations. In simulation 5 there is considerably more GDP growth than in the other simulations, giving fixed factors a more inhibiting role. Employment growth in industries such as Oil & gas, Fruit & nut farms and Oil seed farms in which mineral deposits and land are important will exceed output growth even when K/L is constant. In industries without fixed factors employment growth will equal output growth when K/L is constant. Thus in simulation 5, employment deviations are not completely explained by output deviations. Fixed-factor intensity also has a role, although minor.

3. Concluding remarks

We have created building blocks for assessing the effects on the U.S. economy of programs designed to reduce beef consumption by U.S. households. The next key task is to specify scenarios for the weights on these the building blocks that are realistic for specific programs. For example, if it were found that a beef-tax program could (a) reduce beef consumption by 5 per cent, (b) decrease health costs by 2 per cent and (c) increase labor-force participation by 1 per cent then we could refer to results in Table 2.1 and estimate the medium-term percentage effect on GDP as:

$$gdp = \frac{5}{10} * (-0.003) + \frac{2}{3.32} * (0.121) + \frac{1}{0.39} * (0.374) = 1.03 \text{ per cent}$$

Similarly, if we were concerned with the welfare effects of the program, assessed by real private consumption modified for reductions in health-service requirements, then we could compute

$$\text{welfare} = \frac{5}{10} * (-0.006) + \frac{2}{3.32} * (0.784) + \frac{1}{0.39} * (0.359) = 1.390 \text{ per cent}$$

If our focus were on microeconomic variables then we could turn to Table 2.2 and calculate the effects on the output of Cattle ranching as

$$\text{output}\left(\text{cattle ranching}\right) = \frac{5}{10} * (-6.808) + \frac{2}{3.32} * (0.340) + \frac{1}{0.39} * (0.311) = -2.402 \text{ per cent}$$

Apart from emphasizing the necessity for realistic weighting schemes for combining our building blocks, these examples make it clear that macro effects are determined almost entirely by the weights assigned to health saving and labor-force participation. Mere changes in the structure of consumption away from beef towards other products have negligible macroeconomic effects. On the other hand, important changes in the industry composition of output and employment flow from each of our five building blocks.

A strength of CGE modeling is its ability to combine detailed data with theory that encompasses optimizing behavior by households, industries, capital creators and traders, and market linkages that connect them. In section 2 we undertook a forensic examination of the results from the five building-block simulations to identify the major determining data items and behavioural assumptions. This examination uncovered, among other things, the result-determining roles of:

- the share of expenditure on beef products in U.S. household budgets;
- the share of beef purchases in the expenditures of restaurants and other food-serving industries;
- the dependence of the U.S. economy on imports of beef products compared with its dependence on imports of other food products such as vegetables, fruit and fish;
- the shares of labor, capital and land in primary factor inputs to beef processing and cattle ranching relative to these shares in other food-related industries;
- the size of health costs in the U.S. relative to aggregate private consumption and GDP;
- the share of labor in primary factor inputs to health services;
- the tax treatments of production and consumption of health services relative to the tax treatment of production and consumption of other goods and services;
- the low import dependency of health services;
- household expenditure elasticities for beef and other food products relative to these elasticities for non-food commodities;
- tax-induced efficiency changes in the composition of household expenditure (welfare triangles)
- diminishing economy-wide returns to an expanding U.S. economy associated with fixed factors (land and mineral resources) and declining terms of trade;

- links between investment and the balance of trade, foreign financing of investment and accumulation of net foreign liabilities;
- the difference between the welfare implications of growth based on accumulation of foreign-owned factors of production (foreign-financed capital) and greater use of domestically owned factors of production (increased labor-force participation); and
- the distribution between labor and capital in the medium term of the burden of terms-of-trade and efficiency losses.

Identifying result-determining factors in an intuitive fashion supported by back-of-the-envelope calculations drawing on the model's data and theory is important for two reasons.

First, the process we have followed in section 2 exposes modeling shortcomings. These are more subtle errors than those that can be picked up by mechanical routine tests. Behind the simulations presented in this report are several discarded simulations that were found wanting after careful result-interrogation. For example, examination of the results from an initial version of the beef-tax simulation showed a suspiciously low outcome for private consumption. We eventually traced this to our failure to include the beef-tax revenue in the government accounts. Users of CGE results are wise to be sceptical of results that cannot be supported by detailed justifications.

Second, result-interpretation along the lines of section 2 allows us to communicate in an understandable way what has been taken into account. It also gives a basis for thinking about what has been left out, or what additional factors should be considered. It is a way of exposing the data and theory that are relevant for the results so that they can be critically assessed by people who may not be familiar with the details of the model.

This is a preliminary report. While we have worked hard on specification of the building blocks and interpretation of results, we anticipate that for the final report our colleagues at Johns Hopkins and CSIRO will request clarifications, improvements in result presentation, and examples of simulations that combine the building blocks. We also expect that the building block simulations will be subject to fine tuning. Obvious areas for fine tuning include: the specification of the input composition of the beef substitute (the veggie burger); the values for the parameters governing substitution between different types of food; and the nature of the saving that would flow from diet-related improvements in the health of the U.S. population.

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Appendix 1. Applications of the USAGE model and related publications

This appendix contains a list of USAGE publications on a variety of topics including:

- terrorism (see publications 1, 2, 3, 15)
- stimulus policy (see publications 12, 14, 24)
- trade (see publications 4, 9, 22)
- immigration (see publications 8, 11, 13, 16, 25, 26, 27, 28)
- energy (see publications 5, 19, 20, 21)
- transport infrastructure spending (see publication 10)
- model validation (see publications 6, 18)
- model development (see publications 7, 23)
- health (see publication 17)

Scholarly book chapters

1. Dixon,P.B., M. Jerie, M.T. Rimmer and G. Wittwer (2018), "Rapid assessments of the economic implications of terrorism events using a regional CGE model: creating GRAD-ECAT (**G**eneralized, **R**egional **A**nd **D**ynamic **E**conomic **C**onsequence **A**nalysis **T**ool)", in Okuyama, Y. and A. Rose. (eds.). *Modeling Spatial and Economic Impacts of Disasters*, Heidelberg, Germany: Springer, forthcoming. [

2. Dixon, P.B., M.T. Rimmer and G. Wittwer (2017), "The economic effects of a hypothetical nuclear attack on downtown LA", chapter 12, pp. 211-27, in G. Wittwer (editor), *Multi-regional Dynamic General Equilibrium Modeling of the U.S. economy: USAGE-TERM Development and Applications*, Advances in Applied General Equilibrium Modeling, Springer, Switzerland.

3. Dixon, P.B., M.T. Rimmer, G. Wittwer, A.Z. Rose and N. Heatwole (2017), "Economic consequences of terrorism and natural disasters: the Computable General equilibrium approach", chapter 8, pp. 158-192 in A. Abbas, D. von Winterfeldt and M. Tambe (editors), *Improving Homeland Security Decisions,* Cambridge University Press.

4. Dixon, P.B. and M.T. Rimmer (2016), "A CGE decomposition approach to modelling the effects of trade reform: NAFTA and the US Economy between 1992 and 1998", chapter 2 in H. Hill and J. Menon (editors), *Managing Globalization in the Asian Century: Issues and Challenges,* the Institute of Southeast Asian Studies, Singapore.

5. Dixon, P.B. and M. Rimmer (2014), "CGE modelling as a framework for absorbing specialist information: linking an energy model and a CGE model to analyse U.S. energy policies" chapter 10, pp. 183-200 in G.Das (editor), *Current Issues in International Trade: Methodologies and Development Implications for the World Economy*, Nova Science Publishing.

6. Dixon, P.B. and M.T. Rimmer (2013), "Validation in CGE modeling", Chapter 19, pp. 1271-1330 in P.B. Dixon and D.W. Jorgenson (editors) *Handbook of Computable General Equilibrium Modeling*, Elsevier.

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8. Dixon, P.B. and Maureen T. Rimmer (2010), "U.S. imports of low-skilled labor: restrict or liberalize?", chapter 5, pp. 103-51 in John Gilbert (editor) *New Developments in Computable General Equilibrium Analysis of Trade Policy*, Volume 7 of H. Beladi and K. Choi (series editors) *Frontiers of Economics and Globalization*, Emerald Publishing, UK.

Refereed journal articles

9. Dixon, P.B., M. T. Rimmer and R. Waschik (2017), "Evaluating the effects of local content measures in a CGE model: eliminating the US Buy America(n) programs", *Economic Modelling*, 68, pp.155-166, cited in the *Economist*, Nov 25, 2017, see https://www.economist.com/news/finance-and-economics/21731633-local-content-requirements-make-appealing-slogans-bad-policies-buying-local.

10. Dixon, P.B., M. T. Rimmer and R. Waschik (2017), "Linking CGE and specialist models: Deriving the implications of highway policy using USAGE-Hwy", *Economic Modelling*, vol. 66, pp. 1-18, November.

11. Dixon, P.B., M.T. Rimmer and B.W. Roberts (2014), “Restricting employment of low-paid immigrants: a general equilibrium assessment of the social welfare implications for legal U.S. wage-earners” *Contemporary Economic Policy*, Vol. 32(3), pp. 639-52.

12. Dixon, P.B. and Maureen T. Rimmer (2013), "Doubling U.S. Exports under the President's National Export Initiative: Implications of successful implementation” *Contemporary Economic Policy*, vol. 31(2), pp. 440-56.

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21. Dixon, P.B., Stefan Osborne and Maureen T. Rimmer (2007), “The economy-wide effects in the United States of replacing crude petroleum with biomass”, *Energy and Environment*, 18(6), pp. 709-722.

22. Dixon, P.B., Maureen T. Rimmer and Marinos E. Tsigas (2007), “Regionalizing results from a detailed CGE model: macro, industry and state effects in the U.S. of removing major tariffs and quotas”, *Papers in Regional Science*, Vol. 86(1), March, pp. 31-55.

23. Dixon, P.B. and M.T. Rimmer (2004), “The US economy from 1992 to 1998: results from a detailed CGE model”, *Economic Record*, Vol. 80 (Special Issue), September, pp.S13-S23.

Other research outputs

24. Zahniser, S., T. Hertz, P.B. Dixon and M.T. Rimmer (2017), “The Potential Effects of Increased Demand for U.S. Agricultural Exports on Metro and Nonmetro Employment”, *Economic Research Report No. ERR-227*, April, pp. 4 available at:

    https://www.ers.usda.gov/publications/pub-details/?pubid=83069 .

25. Dixon, P.B. and M.T. Rimmer (2016), “Trump’s immigration policy would push legal U.S. workers down the occupational ladder”, *The Conversation*, available at https://theconversation.com/trumps-immigration-policy-would-push-legal-us-workers-down-the-occupational-ladder-68805 .

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Appendix 2. List of USAGE industries/commodities and aggregation scheme for results in section 2

Table A2.1 is a list of the 392 USAGE commodities. With 9 exceptions these are NAICS categories used by the Bureau of Economic Analysis in their benchmark input-output tables. The 9 exceptions are:

386 Holiday. This is the collection of inputs used by U.S. households when they take a vacation in the U.S. These inputs include items such air transportation, gasoline, hotels, recreation spending and restaurants.

387 Foreign holiday. This is the collection of inputs used by U.S. households when they take a vacation outside the U.S. The main input is non-comparable imports covering hotels and other expenses in foreign countries. Another major input is international air transportation. In USAGE, commodities 386 and 387 are modeled as substitutes in the household utility function.

388 Export tourism. This is the collection of inputs purchased in the U.S. by foreign visitors either on vacation or business.

389 Export education. This is the collection of inputs purchased in the U.S. by foreign students.

390 Other non-residential. This is the collection of inputs purchased in the U.S. by international organizations located in the U.S. and by their foreign employees.

276 & 391 Air transportation domestic and International air transportation . These two commodities/industries are a disaggregation of the NAICS category Air transportation. The two parts refer to services provided through domestic and international flights.

278 & 392 Water transportation domestic and International water transportation . These two commodities/industries are a disaggregation of the NAICS category Water transportation. The two parts refer to services provided through domestic and international shipping.

For 389 of the 392 commodities listed in Table A2.1 there is a corresponding industry. In nearly all cases, the corresponding industry produces the bulk of the economy's output of the commodity and this commodity accounts for the bulk of the industry's output. There are three commodities with no corresponding industry. These are

383 Scrap

384 Used & second-hand good

385 Non-comparable imports

Commodities 383 and 384 are generated by households and are minor outputs or by-products of industries. Commodity 385 is purely imported.

It turns out by chance that there are 392 industries as well as 392 commodities. Three government industries produce a commodity in competition with a private sector industry which bears the name of the commodity. These government industries are: Federal electric utility (produces commodity 22, Power generation), State & local government electric utility (also produces commodity 22); and State & local government passenger transport (produces commodity 280, Ground passenger transport).

In section 2 we report results for aggregated sectors as well as for key individual commodities/industries. Tables A2.1 and A2.2 define the aggregation schemes.

Table A2.1. USAGE com/inds, NAICS description and mappings to 45 and 9 sectors

Com/Ind	Name	NAICS descriptions	Mapping to 45sectors	Mapping to 9 sectors
1	OilSeedFarm	Oilseed farming	OilSeedFarm	Agriculture
2	GrainFarm	Grain farming	GrainFarm	Agriculture
3	VegMelonFarm	Vegetable and melon farming	VegMelonFarm	Agriculture
4	FruitNutFarm	Fruit and tree nut farming	FruitNutFarm	Agriculture
5	GreenNursPrd	Greenhouse, nursery, and floriculture production	GreenNursPrd	Agriculture
6	OthCropFarm	Other crop farming	OthCropFarm	Agriculture
7	CattRancFarm	Beef cattle ranching and farming, including feedlots and dual-purpose ranching and farming	CattRancFarm	Agriculture
8	DairCattProd	Dairy cattle and milk production	DairCattProd	Agriculture
9	OtherAnimal	Animal production, except cattle and poultry and eggs	OtherAnimal	Agriculture
10	PoultryEgg	Poultry and egg production	PoultryEgg	Agriculture
11	ForestLog	Forestry and logging	ForestLog	Agriculture
12	FishHuntTrap	Fishing, hunting and trapping	FishHuntTrap	Agriculture
13	AggForSupp	Support activities for agriculture and forestry	AggForSupp	Agriculture
14	OIlGas	Oil and gas extraction	Mining	Mining
15	Coal	Coal mining	Mining	Mining
16	GoldOthMetl	Iron, gold, silver, and other metal ore mining	Mining	Mining
17	CopNickMine	Copper, nickel, lead, and zinc mining	Mining	Mining
18	Stone	Stone mining and quarrying	Mining	Mining
19	OtherNonMetl	Other nonmetallic mineral mining and quarrying	Mining	Mining
20	OilGasDrill	Drilling oil and gas wells	Mining	Mining
21	OthMineSupp	Other support activities for mining	Mining	Mining
22	PowerGener	Electric power generation, transmission, and distribution	Utilities	Utilities
23	NatGasDist	Natural gas distribution	Utilities	Utilities
24	WaterSewage	Water, sewage and other systems	Utilities	Utilities
25	NResMainRepa	Nonresidential maintenance and repair	Construction	Construction
26	ResMaintRepa	Residential maintenance and repair	Construction	Construction
27	HeaCareStruc	Health care structures	Construction	Construction
28	ManufStruc	Manufacturing structures	Construction	Construction
29	PowComStruc	Power and communication structures	Construction	Construction
30	EducVocStruc	Educational and vocational structures	Construction	Construction
31	HwayStreets	Highways and streets	Construction	Construction
32	ComFarmStruc	Commercial structures, including farm structures	Construction	Construction
33	OthNResStruc	Other nonresidential structures	Construction	Construction
34	SFamResStruc	Single-family residential structures	Construction	Construction
35	MFamResStruc	Multifamily residential structures	Construction	Construction
36	OthResStruc	Other residential structures	Construction	Construction
37	SawWoodPres	Sawmills and wood preservation	ManuOther	ManuOther
38	EngWoodProd	Veneer, plywood, and engineered wood product manufacturing	ManuOther	ManuOther
39	Millwork	Millwork	ManuOther	ManuOther
40	OthWoodProd	All other wood product manufacturing	ManuOther	ManuOther
41	ClayRefrac	Clay product and refractory manufacturing	ManuOther	ManuOther
42	Glass	Glass and glass product manufacturing	ManuOther	ManuOther

Table A2.1 continues …

Table A2.1 continued …

Com/Ind	Name	NAICS descriptions	Mapping to 45 sectors	Mapping to 9 sectors
43	Cement	Cement manufacturing	ManuOther	ManuOther
44	ReadyMix	Ready-mix concrete manufacturing	ManuOther	ManuOther
45	ConcPipeBric	Concrete pipe, brick, and block manufacturing	ManuOther	ManuOther
46	OthConcPrd	Other concrete product manufacturing	ManuOther	ManuOther
47	LimeGypsum	Lime and gypsum product manufacturing	ManuOther	ManuOther
48	Abrasives	Abrasive product manufacturing	ManuOther	ManuOther
49	CutStonePrd	Cut stone and stone product manufacturing	ManuOther	ManuOther
50	GrdMinEarth	Ground or treated mineral and earth manufacturing	ManuOther	ManuOther
51	MinWool	Mineral wool manufacturing	ManuOther	ManuOther
52	MscNonMetMin	Miscellaneous nonmetallic mineral products	ManuOther	ManuOther
53	IronStlManuf	Iron and steel mills and ferroalloy manufacturing	ManuOther	ManuOther
54	PurchStlProd	Steel product manufacturing from purchased steel	ManuOther	ManuOther
55	AlRefManuf	Alumina refining and primary aluminum production	ManuOther	ManuOther
56	PurchAlProd	Aluminum product manufacturing from purchased aluminum	ManuOther	ManuOther
57	CopperSmelt	Primary smelting and refining of copper	ManuOther	ManuOther
58	NonferrMetl	Primary smelting and refining of nonferrous metal (except copper and aluminum	ManuOther	ManuOther
59	CopperProd	Copper rolling, drawing, extruding and alloying	ManuOther	ManuOther
60	NonferMetlPr	Nonferrous metal (except copper and aluminum) rolling, drawing, extruding and alloying	ManuOther	ManuOther
61	FerrFoundry	Ferrous metal foundries	ManuOther	ManuOther
62	NonFerrFound	Nonferrous metal foundries	ManuOther	ManuOther
63	OthForgStmp	All other forging, stamping, and sintering	ManuOther	ManuOther
64	RollForming	Custom roll forming	ManuOther	ManuOther
65	CrwnMtlStamp	Crown and closure manufacturing and metal stamping	ManuOther	ManuOther
66	CutHandTool	Cutlery and handtool manufacturing	ManuOther	ManuOther
67	PlateWork	Plate work and fabricated structural product manufacturing	ManuOther	ManuOther
68	OrnArchMetal	Ornamental and architectural metal products manufacturing	ManuOther	ManuOther
69	Boiler	Power boiler and heat exchanger manufacturing	ManuOther	ManuOther
70	MetalTank	Metal tank (heavy gauge) manufacturing	ManuOther	ManuOther
71	MetalCntnr	Metal can, box, and other metal container (light gauge) manufacturing	ManuOther	ManuOther
72	Hardware	Hardware manufacturing	ManuOther	ManuOther
73	SprnWirePrd	Spring and wire product manufacturing	ManuOther	ManuOther
74	MachShops	Machine shops	ManuOther	ManuOther
75	ScrewNut	Turned product and screw, nut, and bolt manufacturing	ManuOther	ManuOther
76	CoatEngrave	Coating, engraving, heat treating and allied activities	ManuOther	ManuOther
77	Valves	Valve and fittings other than plumbing	ManuOther	ManuOther
78	Plumbing	Plumbing fixture fitting and trim manufacturing	ManuOther	ManuOther
79	BallBearng	Ball and roller bearing manufacturing	ManuOther	ManuOther
80	Ammunition	Ammunition, arms, ordnance, and accessories manufacturing	ManuOther	ManuOther
81	FabPipeFtng	Fabricated pipe and pipe fitting manufacturing	ManuOther	ManuOther

Table A2.1 continues …

Table A2.1 continued …

Com/Ind	Name	NAICS descriptions	Mapping to 45 sectors	Mapping to 9 sectors
82	OthFabMetl	Other fabricated metal manufacturing	ManuOther	ManuOther
83	FarmMach	Farm machinery and equipment manufacturing	ManuOther	ManuOther
84	LawnEquip	Lawn and garden equipment manufacturing	ManuOther	ManuOther
85	ConstMach	Construction machinery manufacturing	ManuOther	ManuOther
86	MinOilMach	Mining and oil and gas field machinery manufacturing	ManuOther	ManuOther
87	OthInduMach	Other industrial machinery manufacturing	ManuOther	ManuOther
88	PlstRbrMach	Plastics and rubber industry machinery manufacturing	ManuOther	ManuOther
89	SemicondMach	Semiconductor machinery manufacturing	ManuOther	ManuOther
90	VendingMach	Vending, commercial laundry, and other commercial and service industry machinery manufacturing	ManuOther	ManuOther
91	OfficeMach	Office machinery manufacturing	ManuOther	ManuOther
92	OptInstLens	Optical instrument and lens manufacturing	ManuOther	ManuOther
93	PhotoEquip	Photographic and photocopying equipment manufacturing	ManuOther	ManuOther
94	AirPurVentil	Air purification and ventilation equipment manufacturing	ManuOther	ManuOther
95	HeatingEq	Heating equipment (except warm air furnaces) manufacturing	ManuOther	ManuOther
96	ACRefrig	Air conditioning, refrigeration, and warm air heating equipment manufacturing	ManuOther	ManuOther
97	MoldMfg	Industrial mold manufacturing	ManuOther	ManuOther
98	RollMillMach	Metal cutting and forming machine tool manufacturing	ManuOther	ManuOther
99	ToolDieJig	Special tool, die, jig, and fixture manufacturing	ManuOther	ManuOther
100	MtlWorkMach	Cutting and machine tool accessory, rolling mill, and other metalworking machinery manufacturing	ManuOther	ManuOther
101	Turbine	Turbine and turbine generator set units manufacturing	ManuOther	ManuOther
102	GearManuf	Speed changer, industrial high-speed drive, and gear manufacturing	ManuOther	ManuOther
103	MechPowTrans	Mechanical power transmission equipment manufacturing	ManuOther	ManuOther
104	OthEngEquip	Other engine equipment manufacturing	ManuOther	ManuOther
105	Pumps	Pump and pumping equipment manufacturing	ManuOther	ManuOther
106	AirGasCmprs	Air and gas compressor manufacturing	ManuOther	ManuOther
107	MatlHandl	Material handling equipment manufacturing	ManuOther	ManuOther
108	PdrivnHandTl	Power-driven handtool manufacturing	ManuOther	ManuOther
109	Scales	Other general purpose machinery manufacturing	ManuOther	ManuOther
110	PackngMach	Packaging machinery manufacturing	ManuOther	ManuOther
111	IndFurnace	Industrial process furnace and oven manufacturing	ManuOther	ManuOther
112	FluidPower	Fluid power process machinery	ManuOther	ManuOther
113	Computers	Electronic computer manufacturing	ManuOther	ManuOther
114	CmptrStorage	Computer storage device manufacturing	ManuOther	ManuOther
115	CompTermin	Computer terminals and other computer peripheral equipment manufacturing	ManuOther	ManuOther
116	Telephone	Telephone apparatus manufacturing	ManuOther	ManuOther
117	BroadcastEq	Broadcast and wireless communications equipment	ManuOther	ManuOther

Table A2.1 continues …

Table A2.1 continued …

Com/Ind	Name	NAICS descriptions	Mapping to 45 sectors	Mapping to 9 sectors
118	CommunEquip	Other communications equipment manufacturing	ManuOther	ManuOther
119	AudVidEquip	Audio and video equipment manufacturing	ManuOther	ManuOther
120	OtElectrnic	Other electronic component manufacturing	ManuOther	ManuOther
121	Semicondctr	Semiconductor and related device manufacturing	ManuOther	ManuOther
122	PrintCircuit	Printed circuit assembly (electronic assembly) manufacturing	ManuOther	ManuOther
123	ElectroMedic	Electromedical and electrotherapeutic apparatus manufacturing	ManuOther	ManuOther
124	SearchNavig	Search, detection, and navigation instruments manufacturing	ManuOther	ManuOther
125	EnviroContrl	Automatic environmental control manufacturing	ManuOther	ManuOther
126	ProcVblInsts	Industrial process variable instruments manufacturing	ManuOther	ManuOther
127	FluidMeters	Totalizing fluid meter and counting device manufacturing	ManuOther	ManuOther
128	ElecTestInst	Electricity and signal testing instruments manufacturing	ManuOther	ManuOther
129	LabInsts	Analytical laboratory instrument manufacturing	ManuOther	ManuOther
130	RadiationIns	Irradiation apparatus manufacturing	ManuOther	ManuOther
131	WatchClock	Watch, clock, and other measuring and controlling device manufacturing	ManuOther	ManuOther
132	MagOptiMedia	Manufacturing and reproducing magnetic and optical media	ManuOther	ManuOther
133	Lightbulbs	Electric lamp bulb and part manufacturing	ManuOther	ManuOther
134	LightFxtr	Lighting fixture manufacturing	ManuOther	ManuOther
135	SmAppliaMf	Small electrical appliance manufacturing	ManuOther	ManuOther
136	HshldStove	Household cooking appliance manufacturing	ManuOther	ManuOther
137	HshldFridge	Household refrigerator and home freezer manufacturing	ManuOther	ManuOther
138	HshldLaundry	Household laundry equipment manufacturing	ManuOther	ManuOther
139	OthHshldApp	Other major household appliance manufacturing	ManuOther	ManuOther
140	PwrTrnsfrmr	Power, distribution, and specialty transformer manufacturing	ManuOther	ManuOther
141	MotorGenratr	Motor and generator manufacturing	ManuOther	ManuOther
142	Switchboard	Switchgear and switchboard apparatus manufacturing	ManuOther	ManuOther
143	Relays	Relay and industrial control manufacturing	ManuOther	ManuOther
144	StorBattery	Storage battery manufacturing	ManuOther	ManuOther
145	PrimBatter	Primary battery manufacturing	ManuOther	ManuOther
146	ComElecWire	Communication and energy wire and cable manufacturing	ManuOther	ManuOther
147	WireDevice	Wiring device manufacturing	ManuOther	ManuOther
148	CarbonProds	Carbon and graphite product manufacturing	ManuOther	ManuOther
149	MsElEquip	All other miscellaneous electrical equipment and component manufacturing	ManuOther	ManuOther
150	Autombile	Automobile manufacturing	ManuOther	ManuOther
151	LightTruck	Light truck and utility vehicle manufacturing	ManuOther	ManuOther
152	HeavyTruck	Heavy duty truck manufacturing	ManuOther	ManuOther
153	VehicleBody	Motor vehicle body manufacturing	ManuOther	ManuOther

Table A2.1 continues …

Table A2.1 continued …

Com/Ind	Name	NAICS descriptions	Mapping to 45 sectors	Mapping to 9 sectors
154	TruckTrailer	Truck trailer manufacturing	ManuOther	ManuOther
155	MotorHome	Motor home manufacturing	ManuOther	ManuOther
156	TravlTrlr	Travel trailer and camper manufacturing	ManuOther	ManuOther
157	GasEngPrts	Motor vehicle gasoline engine and engine parts manufacturing	ManuOther	ManuOther
158	ElecEngPrts	Motor vehicle electrical and electronic equipment manufactur	ManuOther	ManuOther
159	SteerBrake	Motor vehicle steering, suspension component (except spring)	ManuOther	ManuOther
160	PwrTrainPrts	Motor vehicle transmission and power train parts manufacturi	ManuOther	ManuOther
161	SeatingInter	Motor vehicle seating and interior trim manufacturing	ManuOther	ManuOther
162	AutoMtlStamp	Motor vehicle metal stamping	ManuOther	ManuOther
163	OthAuto	Other motor vehicle parts manufacturing	ManuOther	ManuOther
164	Aircraft	Aircraft manufacturing	ManuOther	ManuOther
165	AirEngines	Aircraft engine and engine parts manufacturing	ManuOther	ManuOther
166	OthAirParts	Other aircraft parts and auxiliary equipment manufacturing	ManuOther	ManuOther
167	Missiles	Guided missile and space vehicle manufacturing	ManuOther	ManuOther
168	MissilPrts	Propulsion units and parts for space vehicles and guided mis	ManuOther	ManuOther
169	RlrdCars	Railroad rolling stock manufacturing	ManuOther	ManuOther
170	Ships	Ship building and repairing	ManuOther	ManuOther
171	Boats	Boat building	ManuOther	ManuOther
172	MotrBikes	Motorcycle, bicycle, and parts manufacturing	ManuOther	ManuOther
173	ArmyTanks	Military armored vehicle, tank, and tank component manufactu	ManuOther	ManuOther
174	OthrTransEq	All other transportation equipment manufacturing	ManuOther	ManuOther
175	WoodKitcCabt	Wood kitchen cabinet and countertop manufacturing	ManuOther	ManuOther
176	UphlHldFurn	Upholstered household furniture manufacturing	ManuOther	ManuOther
177	NonUpHhlFurn	Nonupholstered wood household furniture manufacturing	ManuOther	ManuOther
178	OthInsHhFurn	Other household nonupholstered furniture	ManuOther	ManuOther
179	InstFurn	Institutional furniture manufacturing	ManuOther	ManuOther
180	OfficeFurn	Office furniture and custom architectural woodwork and millw	ManuOther	ManuOther
181	ShcaseShlv	Showcase, partition, shelving, and locker manufacturing	ManuOther	ManuOther
182	OthFurn	Other furniture related product manufacturing	ManuOther	ManuOther
183	SrgMedInst	Surgical and medical instrument manufacturing	ManuOther	ManuOther
184	SurgAppSupp	Surgical appliance and supplies manufacturing	ManuOther	ManuOther
185	DentalEquip	Dental equipment and supplies manufacturing	ManuOther	ManuOther
186	Ophthalmic	Ophthalmic goods manufacturing	ManuOther	ManuOther
187	DentalLab	Dental laboratories	ManuOther	ManuOther
188	Jewelry	Jewelry and silverware manufacturing	ManuOther	ManuOther
189	SportGoods	Sporting and athletic goods manufacturing	ManuOther	ManuOther
190	Toys	Doll, toy, and game manufacturing	ManuOther	ManuOther
191	OfficSupply	Office supplies (except paper) manufacturing	ManuOther	ManuOther
192	Signs	Sign manufacturing	ManuOther	ManuOther
193	AllOthManuf	All other miscellaneous manufacturing	ManuOther	ManuOther

Table A2.1 continues …

Table A2.1 continued …

Com/Ind	Name	NAICS descriptions	Mapping to 45 sectors	Mapping to 9 sectors
194	DogCatFood	Dog and cat food manufacturing	ManuOther	ManuOther
195	OthAnFood	Other animal food manufacturing	ManuOther	ManuOther
196	FlourMalMill	Flour milling and malt manufacturing	FlourMalMill	FoodManu
197	WetCornMill	Wet corn milling	WetCornMill	FoodManu
198	SoyOilProc	Soybean and other oilseed processing	SoyOilProc	FoodManu
199	FatsOils	Fats and oils refining and blending	FatsOils	FoodManu
200	BrkCereal	Breakfast cereal manufacturing	BrkCereal	FoodManu
201	SugarConfec	Sugar and confectionery product manufacturing	SugarConfec	FoodManu
202	FrozFood	Frozen food manufacturing	FrozFood	FoodManu
203	FrtVegCDry	Fruit and vegetable canning, pickling, and drying	FrtVegCDry	FoodManu
204	MilkButter	Fluid milk and butter manufacturing	MilkButter	FoodManu
205	Cheese	Cheese manufacturing	Cheese	FoodManu
206	DCEDairy	Dry, condensed, and evaporated dairy product manufacturing	DCEDairy	FoodManu
207	IceCream	Ice cream and frozen dessert manufacturing	IceCream	FoodManu
208	AnimalProc	Animal (except poultry) slaughtering, rendering, and process	AnimalProc	FoodManu
209	PoultryProc	Poultry processing	PoultryProc	FoodManu
210	Seafood	Seafood product preparation and packaging	Seafood	FoodManu
211	BreadBakery	Bread and bakery product manufacturing	BreadBakery	FoodManu
212	CookiePasta	Cookie, cracker, pasta, and tortilla manufacturing	CookiePasta	FoodManu
213	SnackFood	Snack food manufacturing	SnackFood	FoodManu
214	CoffTea	Coffee and tea manufacturing	CoffTea	FoodManu
215	FlavorSyrup	Flavoring syrup and concentrate manufacturing	FlavorSyrup	FoodManu
216	SeasDressing	Seasoning and dressing manufacturing	SeasDressing	FoodManu
217	OthrFoodMf	All other food manufacturing	OthrFoodMf	FoodManu
218	SoftDrinks	Soft drink and ice manufacturing	SoftDrinks	FoodManu
219	Breweries	Breweries	ManuOther	ManuOther
220	Wineries	Wineries	ManuOther	ManuOther
221	Distilleries	Distilleries	ManuOther	ManuOther
222	Tobacco	Tobacco product manufacturing	ManuOther	ManuOther
223	FiberYarn	Fiber, yarn, and thread mills	ManuOther	ManuOther
224	FabricMills	Fabric mills	ManuOther	ManuOther
225	TextFabrCoat	Textile and fabric finishing and fabric coating mills	ManuOther	ManuOther
226	Carpet	Carpet and rug mills	ManuOther	ManuOther
227	CurtainLinen	Curtain and linen mills	ManuOther	ManuOther
228	OthTextMills	Other textile product mills	ManuOther	ManuOther
229	ApparelMf	Apparel manufacturing	ManuOther	ManuOther
230	LeatherMf	Leather and allied product manufacturing	ManuOther	ManuOther
231	PulpMills	Pulp mills	ManuOther	ManuOther
232	Paper	Paper mills	ManuOther	ManuOther
233	Paperboard	Paperboard mills	ManuOther	ManuOther
234	PprContainer	Paperboard container manufacturing	ManuOther	ManuOther
235	PprBagTreat	Paper bag and coated and treated paper manufacturing	ManuOther	ManuOther
236	Stationry	Stationery product manufacturing	ManuOther	ManuOther
237	SanitPpr	Sanitary paper product manufacturing	ManuOther	ManuOther
238	OthPprProd	All other converted paper product manufacturing	ManuOther	ManuOther
239	Printing	Printing	ManuOther	ManuOther

Table A2.1 continues …

Table A2.1 continued …

Com/Ind	Name	NAICS descriptions	Mapping to 45 sectors	Mapping to 9 sectors
240	SuppPrint	Support activities for printing	ManuOther	ManuOther
241	PetrolRefine	Petroleum refineries	ManuOther	ManuOther
242	AsphaltPave	Asphalt paving mixture and block manufacturing	ManuOther	ManuOther
243	AsphltShngl	Asphalt shingle and coating materials manufacturing	ManuOther	ManuOther
244	OthPetroCoal	Other petroleum and coal products manufacturing	ManuOther	ManuOther
245	Petrochem	Petrochemical manufacturing	ManuOther	ManuOther
246	IndGas	Industrial gas manufacturing	ManuOther	ManuOther
247	SynthDye	Synthetic dye and pigment manufacturing	ManuOther	ManuOther
248	OthInorgChem	Other basic inorganic chemical manufacturing	ManuOther	ManuOther
249	OthOrgChem	Other basic organic chemical manufacturing	ManuOther	ManuOther
250	Plastics	Plastics material and resin manufacturing	ManuOther	ManuOther
251	SynRubbFiber	Synthetic rubber and artificial and synthetic fibers and fil	ManuOther	ManuOther
252	Fertilizer	Fertilizer manufacturing	ManuOther	ManuOther
253	Pesticide	Pesticide and other agricultural chemical manufacturing	ManuOther	ManuOther
254	MedicBotanic	Medicinal and botanical manufacturing	ManuOther	ManuOther
255	Pharma	Pharmaceutical preparation manufacturing	ManuOther	ManuOther
256	InVitroDiag	In-vitro diagnostic substance manufacturing	ManuOther	ManuOther
257	BiologicProd	Biological product (except diagnostic) manufacturing	ManuOther	ManuOther
258	Paint	Paint and coating manufacturing	ManuOther	ManuOther
259	Adhesives	Adhesive manufacturing	ManuOther	ManuOther
260	Soap	Soap and cleaning compound manufacturing	ManuOther	ManuOther
261	ToiletPrep	Toilet preparation manufacturing	ManuOther	ManuOther
262	Ink	Printing ink manufacturing	ManuOther	ManuOther
263	OthChemical	All other chemical product and preparation manufacturing	ManuOther	ManuOther
264	PlstPacking	Plastics packaging materials and unlaminated film and sheet	ManuOther	ManuOther
265	PlstPipe	Plastics pipe, pipe fitting, and unlaminated profile shape m	ManuOther	ManuOther
266	LamPlstPlate	Laminated plastics plate, sheet (except packaging), and shap	ManuOther	ManuOther
267	Polystyrene	Polystyrene foam product manufacturing	ManuOther	ManuOther
268	UrethaneFoam	Urethane and other foam product (except polystyrene) manufac	ManuOther	ManuOther
269	PlstBottle	Plastics bottle manufacturing	ManuOther	ManuOther
270	OthPlastic	Other plastics product manufacturing	ManuOther	ManuOther
271	Tires	Tire manufacturing	ManuOther	ManuOther
272	RbrPlstHose	Rubber and plastics hoses and belting manufacturing	ManuOther	ManuOther
273	OthRbrProd	Other rubber product manufacturing	ManuOther	ManuOther
274	WholesaleTr	Wholesale trade	OtherServ	OtherServ
275	RetailTr	Other retail	OtherServ	OtherServ
276	AirTrans	Air transportation, domestic	OtherServ	OtherServ
277	RailTrans	Rail transportation	OtherServ	OtherServ
278	WaterTrans	Water transportation, domestic	OtherServ	OtherServ
279	TruckTrans	Truck transportation	OtherServ	OtherServ
280	GrdPassTrans	Transit and ground passenger transportation	OtherServ	OtherServ

Table A2.1 continues …

Table A2.1 continued …

Com/Ind	Name	NAICS descriptions	Mapping to 45 sectors	Mapping to 9 sectors
281	Pipeline	Pipeline transportation	OtherServ	OtherServ
282	ScenSuppTran	Scenic and sightseeing transportation and support activities	OtherServ	OtherServ
283	Couriers	Couriers and messengers	OtherServ	OtherServ
284	Warehousing	Warehousing and storage	OtherServ	OtherServ
285	NewspaperPb	Newspaper publishers	OtherServ	OtherServ
286	PerdclPub	Periodical Publishers	OtherServ	OtherServ
287	BookPub	Book publishers	OtherServ	OtherServ
288	DataPub	Directory, mailing list, and other publishers	OtherServ	OtherServ
289	SoftwrPub	Software publishers	OtherServ	OtherServ
290	MoviesVideo	Motion picture and video industries	OtherServ	OtherServ
291	SoundRecord	Sound recording industries	OtherServ	OtherServ
292	RadTVBroad	Radio and television broadcasting	OtherServ	OtherServ
293	Cable	Cable and other subscription programming	OtherServ	OtherServ
294	WiredTelco	Wired telecommunications carriers	OtherServ	OtherServ
295	WirelesTelco	Wireless telecommunications carriers (except satellite)	OtherServ	OtherServ
296	SatOthTelco	Satellite, telecommunications resellers, and all other telec	OtherServ	OtherServ
297	DataHostServ	Data processing, hosting, and related services	OtherServ	OtherServ
298	NewsInfoServ	News syndicates, libraries, archives and all other informati	OtherServ	OtherServ
299	NetPubSearch	Internet publishing and broadcasting and Web search portals	OtherServ	OtherServ
300	MonetDepCred	Monetary authorities and depository credit intermediation	OtherServ	OtherServ
301	NonDepCredit	Nondepository credit intermediation and related activities	OtherServ	OtherServ
302	SecComBroker	Securities and commodity contracts intermediation and broker	OtherServ	OtherServ
303	OthFinance	Other financial investment activities	OtherServ	OtherServ
304	InsCarriers	Insurance carriers	OtherServ	OtherServ
305	InsBrokers	Insurance agencies, brokerages, and related activities	OtherServ	OtherServ
306	FundsTrusts	Funds, trusts, and other financial vehicles	OtherServ	OtherServ
307	Housing	Housing	OtherServ	OtherServ
308	OthRealEst	Other real estate	OtherServ	OtherServ
309	AutoRental	Automotive equipment rental and leasing	OtherServ	OtherServ
310	GenrlRentl	Consumer goods and general rental centers	OtherServ	OtherServ
311	MachEquRntl	Commercial and industrial machinery and equipment rental and	OtherServ	OtherServ
312	AssetLessors	Lessors of nonfinancial intangible assets	OtherServ	OtherServ
313	LegalSvces	Legal services	OtherServ	OtherServ
314	CustCptrProg	Custom computer programming services	OtherServ	OtherServ
315	cptrSysDesgn	Computer systems design services	OtherServ	OtherServ
316	OthCptrSvce	Other computer related services, including facilities manage	OtherServ	OtherServ
317	Accounting	Accounting, tax preparation, bookkeeping, and payroll servic	OtherServ	OtherServ
318	ArchEngSvce	Architectural, engineering, and related services	OtherServ	OtherServ
319	DesignSvce	Specialized design services	OtherServ	OtherServ
320	MgmtCnsltSv	Management consulting services	OtherServ	OtherServ

Table A2.1 continues …

Table A2.1 continued …

Com/Ind	Name	NAICS descriptions	Mapping to 45 sectors	Mapping to 9 sectors
321	EnvCnsltSvc	Environmental and other technical consulting services	OtherServ	OtherServ
322	ResDevelSvc	Scientific research and development services	OtherServ	OtherServ
323	Advertising	Advertising, public relations, and related services	OtherServ	OtherServ
324	MscProfSvces	Marketing research and all other miscellaneous professional,	OtherServ	OtherServ
325	PhotoSvce	Photographic services	OtherServ	OtherServ
326	VetSvces	Veterinary services	OtherServ	OtherServ
327	CompanyMgmt	Management of companies and enterprises	OtherServ	OtherServ
328	OffAdmSvces	Office administrative services	OtherServ	OtherServ
329	FacilSupSvc	Facilities support services	OtherServ	OtherServ
330	EmplSvce	Employment services	OtherServ	OtherServ
331	BusnsSupSvc	Business support services	OtherServ	OtherServ
332	TravelSvce	Travel arrangement and reservation services	OtherServ	OtherServ
333	DetectivSvce	Investigation and security services	OtherServ	OtherServ
334	BldgSvce	Services to buildings and dwellings	OtherServ	OtherServ
335	OthSuppSvce	Other support services	OtherServ	OtherServ
336	WasteMgmt	Waste management and remediation services	OtherServ	OtherServ
337	EleSecSchool	Elementary and secondary schools	OtherServ	OtherServ
338	Colleges	Junior colleges, colleges, universities, and professional sc	OtherServ	OtherServ
339	OtherEducSv	Other educational services	OtherServ	OtherServ
340	Physician	Offices of physicians	HealthServ	HealthServ
341	Dentists	Offices of dentists	HealthServ	HealthServ
342	OthHealth	Offices of other health practitioners	HealthServ	HealthServ
343	Outpatient	Outpatient care centers	HealthServ	HealthServ
344	MedDiagLab	Medical and diagnostic laboratories	HealthServ	HealthServ
345	HomeHlthSvc	Home health care services	HealthServ	HealthServ
346	OthAmbul	Other ambulatory health care services	HealthServ	HealthServ
347	Hospitals	Hospitals	HealthServ	HealthServ
348	NursingHome	Nursing and community care facilities	HealthServ	HealthServ
349	MentlHealth	Residential mental retardation, mental health, substance abu	HealthServ	HealthServ
350	IndFamHealth	Individual and family services	HealthServ	HealthServ
351	SocialSvce	Community food, housing, and other relief services, includin	OtherServ	OtherServ
352	ChildCare	Child day care services	OtherServ	OtherServ
353	PerfArts	Performing arts companies	OtherServ	OtherServ
354	SpectSports	Spectator sports	OtherServ	OtherServ
355	Promoters	Promoters of performing arts and sports and agents for publi	OtherServ	OtherServ
356	IndArtists	Independent artists, writers, and performers	OtherServ	OtherServ
357	MuseumZoo	Museums, historical sites, zoos, and parks	OtherServ	OtherServ
358	AmusePark	Amusement parks and arcades	OtherServ	OtherServ
359	Gambling	Gambling industries (except casino hotels)	OtherServ	OtherServ
360	OthAmuse	Other amusement and recreation industries	OtherServ	OtherServ
361	AccHotels	Accommodation	AccHotels	FoodServ
362	FullResto	Full-service restaurants	FullResto	FoodServ
363	LimResto	Limited-service restaurants	LimResto	FoodServ
364	OthFoodDrink	All other food and drinking places	OtherServ	OtherServ

Table A2.1 continues …

Table A2.1 continued …

Com/Ind	Name	NAICS descriptions	Mapping to 45sectors	Mapping to 9 sectors
365	AutoRepair	Automotive repair and maintenance	OtherServ	OtherServ
366	ElEquiRepair	Electronic and precision equipment repair and maintenance	OtherServ	OtherServ
367	MachinerRp	Commercial and industrial machinery and equipment repair and	OtherServ	OtherServ
368	HhGoodsRpr	Personal and household goods repair and maintenance	OtherServ	OtherServ
369	PersCareSvce	Personal care services	OtherServ	OtherServ
370	DeathCareSv	Death care services	OtherServ	OtherServ
371	CleanLaundry	Dry-cleaning and laundry services	OtherServ	OtherServ
372	OthPerSvce	Other personal services	OtherServ	OtherServ
373	ReligiousOrg	Religious organizations	OtherServ	OtherServ
374	GrantOrg	Grantmaking, giving, and social advocacy organizations	OtherServ	OtherServ
375	CivSocialOr	Civic, social, professional, and similar organizations	OtherServ	OtherServ
376	PrivHhlds	Private households	OtherServ	OtherServ
377	FedGovDef	Federal general government (defense)	OtherServ	OtherServ
378	FedGovNonDef	Federal general government (nondefense)	OtherServ	OtherServ
379	PostalSvc	Postal service	OtherServ	OtherServ
380	OthFedGEnt	Other federal government enterprises	OtherServ	OtherServ
381	SLG	State and local general government	OtherServ	OtherServ
382	OthSLGEnt	Other state and local government enterprises	OtherServ	OtherServ
383	Scrap	Scrap	OtherServ	OtherServ
384	Used2HndGds	Used and secondhand goods	OtherServ	OtherServ
385	NoncompImprt	Noncomparable imports	OtherServ	OtherServ
386	Holiday	Vacation	OtherServ	OtherServ
387	FgnHol	Foreign vacation	OtherServ	OtherServ
388	ExpTour	Export tourism	OtherServ	OtherServ
389	ExpEdu	Export education	OtherServ	OtherServ
390	OthNonRes	Othe non-residential spending	OtherServ	OtherServ
391	AirInt	Internatinal air transport	OtherServ	OtherServ
392	WatInt	International water transport	OtherServ	OtherServ

Table A2.2. Aggregated schemes used in Tables 2.2 and 2.3[*]

No.	Aggregated 45 sectors	Aggregated 9 sectors	No.
		Agriculture	1
1	OilSeedFarm		
2	GrainFarm		
3	VegMelonFarm		
4	FruitNutFarm		
5	GreenNursPrd		
6	OthCropFarm		
7	CattRancFarm		
8	DairCattProd		
9	OtherAnimal		
10	PoultryEgg		
11	ForestLog		
12	FishHuntTrap		
13	AggForSupp		
14	Mining	Mining	2
15	Utilities	Utilities	3
16	Construction	Construction	4
17	ManuOther	ManuOther	5
		FoodManu	6
18	FlourMalMill		
19	WetCornMill		
20	SoyOilProc		
21	FatsOils		
22	BrkCereal		
23	SugarConfec		
24	FrozFood		
25	FrtVegCDry		
26	MilkButter		
27	Cheese		
28	DCEDairy		
29	IceCream		
30	BeefProc		
31	OthyAnimProc		
32	PoultryProc		
33	Seafood		
34	BreadBakery		
35	CookiePasta		
36	SnackFood		
37	CoffTea		
38	FlavorSyrup		
39	SeasDressing		
40	OthrFoodMf		
41	SoftDrinks		
42	OtherServ	OtherServ	7
43	HealthServ	HealthServ	8
		FoodServ	9
44	AccHotels		
45	FullResto		
46	LimResto		

*** Tables 2.2 and 2.3 display results for the 45 commodities/industries in the left panel plus the 3 shaded aggregates in the right panel**

Appendix 3. The theory of nesting and its application in USAGE-Food

Production functions

In standard versions of USAGE, industry production functions have 3 levels of nests. At the first level, output of an industry is a function of Composite genuine input and Other costs[8]. At the second level, Composite Genuine input is a function of Primary-factor input and inputs of intermediates undifferentiated by source. At the third level, Primary-factor input is a function of labor, capital and land, and Undifferentiated intermediates are functions of domestic and imported varieties.

To allow substitution effects in USAGE-Food in industries such as restaurants between different commodity inputs from the food sector, we modify the production functions to allow for 4 levels of nests.

Here we start by setting out the general theory of input demand arising from cost-minimization subject to a 4-level nested production in which all nests are CES. Then we consider the particular nesting structure in USAGE-Food.

Production function with 4-level CES nests: general case.

$$X0 = CES1\left(\frac{X1(i)}{A1(i)} \quad i = 1,...,C1\right) \qquad \text{(L1P)}$$

$$X1(i) = CES2\left(\frac{X2(i,f)}{A2(i,f)} \quad f = 1,...,C2(i)\right) \text{ for } i = 1, ..., C1 \qquad \text{(L2P)}$$

$$X2(i,f) = CES3\left(\frac{X3(i,f,k)}{A3(i,f,k)} \quad k = 1,...,C3(i,f)\right) \text{ for } i = 1, ..., C1 \text{ and } f = 1, ..., C2(i) \qquad \text{(L3P)}$$

$$X3(i,f,k) = CES4\left(\frac{X4(i,f,k,s)}{A4(i,f,k,s)} \quad s = 1,...,C3(i,f,k)\right) \qquad \text{(L4P)}$$

for i = 1, ..., C1; f = 1, ..., C2(i); k = 1, ..., C3(i,f)

X0 is total inputs to production in an industry.

X1(i) is the i^{th} level-1 input that creates total input. C1 is the number of items at level 1.

X2(i,f) is the f^{th} input in the nest at level 2 that creates the i item at level 1. C2(i) is the number of items in the nest at level 2 that create the i item in level 1.

X3(i,f,k) is the k^{th} input in the nest at level 3 that creates the (i,f) item at level 2. C3(i,f) is the number of items in the nest at level 3 that create the (i,f) item in level 2.

X4(i,f,k,s) is the s^{th} input in the nest at level 4 that creates the (i,f,k) item at level 3. C4(i,f,k) is the number of items in the nest at level 4 that create the (i,f,k) item in level 3.

The A's are input-saving or using technical change or taste change variables.

Input-demand functions in percentage change form

Under cost-minimizing assumptions, we obtain:

[8] Other costs are an artificial input used to fill in discrepancies between the total observed cost of inputs and the observed value of output.

$$x1(i)-a1(i)=x0-\sigma1\left(p1(i)-\sum_{t\in C1}S1(t)*p1(t)\right)-\sigma1\left(a1(i)-\sum_{t\in C1}S1(t)*a1(t)\right) \quad \text{for } i=1,\ldots,C1 \tag{1}$$

$$p1(i)=\sum_{f\in C2(i)}S2(i,f)*p2(i,f)+\sum_{f\in C2(i)}S2(i,f)*a2(i,f) \quad \text{for } i=1,\ldots,C1 \tag{2}$$

$$x2(i,f)-a2(i,f)=x1(i)-\sigma2(i)\left(p2(i,f)-\sum_{t\in C2(i)}S2(i,t)*p2(i,t)\right) -\sigma2(i)\left(a2(i,f)-\sum_{t\in C2(i)}S2(i,t)*a2(i,t)\right) \quad \text{for } i=1,\ldots,C1; f=1,\ldots,C2(i) \tag{3}$$

$$p2(i,f)=\sum_{k\in C3(i,f)}S3(i,f,k)*p3(i,f,k)+\sum_{k\in C3(i,f)}S3(i,f,k)*a3(i,f,k) \quad \text{for } i=1,\ldots,C1; f=1,\ldots,C2(i) \tag{4}$$

$$x3(i,f,k)-a3(i,f,k)=x2(i,f)-\sigma3(i,f)\left(p3(i,f,k)-\sum_{t\in C3(i,f)}S3(i,f,t)*p3(i,f,t)\right) -\sigma3(i,f)\left(a3(i,f,k)-\sum_{t\in C3(i,f)}S3(i,f,t)*a3(i,f,t)\right) \quad \text{for } i=1,\ldots,C1; f=1,\ldots,C2(i); k=1,\ldots,C3(i,f) \tag{5}$$

$$p3(i,f,k)=\sum_{s\in C4(i,f,k)}S4(i,f,k,s)*p4(i,f,k,s)+\sum_{s\in C4(i,f,k)}S4(i,f,k,s)*a4(i,f,k,s) \quad \text{for } i=1,\ldots,C1; f=1,\ldots,C2(i); k=1,\ldots,C3(i,f) \tag{6}$$

$$x4(i,f,k,s)-a4(i,f,k,s)=x3(i,f,k) -\sigma4(i,f,k)\left(p4(i,f,k,s)-\sum_{t\in C4(i,f,k)}S4(i,f,k,t)*p4(i,f,k,t)\right) -\sigma4(i,f,k)\left(a4(i,f,k,s)-\sum_{t\in C4(i,f,k)}S4(i,f,k,t)*a4(i,f,k,t)\right) \quad \text{for } i=1,\ldots,C1; f=1,\ldots,C2(i); k=1,\ldots,C3(i,f); s=1,\ldots,C4(i,f,k) \tag{7}$$

In these equations the lowercase x, a and p variables refer to percentage changes in quantities, prices and technology variables. The uppercase S's refer to cost shares. S1(i) is the share of level-1 input i in the cost of all level-1 inputs, e.g. the share of Composite input in the total cost of Composite input and Other cost. S2(i,f) is the share in the total cost of level-1 input i accounted for by the f^{th} input in the nest at level 2 that makes up level-1 input i. S3(i,f k) is the share in the total cost of level-2 input (i,f) accounted for by the k^{th} input in the nest at level 3 that makes up level-2 input (i,f). S4(i,f k,s) is the share in the total cost of level-3 input (i,f,k) accounted for by the s^{th} input in the nest at level 4 that makes up level-3 input (i,f,k). The parameters σ1, σ2(i), σ3(i,f) and σ4(i,f,k) are substitution elasticities occurring in the 4 nests.

We adopt the convention that technical change takes place only at level 4. This is not limiting. For example, if we wanted to simulate a technical change that saved 1 per cent of the first input at level 2 in an industry then, in the absence of the a2(1,1) option, we can achieve the desired result by setting a4(1,1,k,s) =-1 for all k= 1, …, C3(1,1) and s= 1, C4(1,1,k).

With this simplification (1) to (7) reduce to (1b) to (7b):

$$x1(i) = x0 - \sigma1\left(p1(i) - \sum_{t \in C1} S1(t) * p1(t) \right) \qquad \text{for } i = 1,\dots,C1 \tag{1b}$$

$$p1(i) = \sum_{f \in C2(i)} S2(i,f) * p2(i,f) \quad \text{for } i = 1,\dots,C1 \tag{2b}$$

$$x2(i,f) = x1(i) - \sigma2(i)\left(p2(i,f) - \sum_{t \in C2(i)} S2(i,t) * p2(i,t) \right) \quad \text{for } i = 1,\dots,C1; f = 1,\dots,C2(i) \tag{3b}$$

$$p2(i,f) = \sum_{k \in C3(i,f)} S3(i,f,k) * p3(i,f,k) \qquad \text{for } i = 1,\dots,C1;\ f = 1,\dots,C2(i) \tag{4b}$$

$$x3(i,f,k) = x2(i,f) - \sigma3(i,f)\left(p3(i,f,k) - \sum_{t \in C3(i,f)} S3(i,f,t) * p3(i,f,t) \right) \quad \text{for } i = 1,\dots,C1; f = 1,\dots,C2(i); k = 1,\dots,C3(i,f) \tag{5b}$$

$$p3(i,f,k) = \sum_{s \in C4(i,f,k)} S4(i,f,k,s) * p4(i,f,k,s) + \sum_{s \in C4(i,f,k)} S4(i,f,k,s) * a4(i,f,k,s) \quad \text{for } i = 1,\dots,C1;\ f = 1,\dots,C2(i); k = 1,\dots,C3(i,f) \tag{6b}$$

$$\begin{aligned} x4(i,f,k,s) - a4(i,f,k,s) &= x3(i,f,k) \\ &- \sigma4(i,f,k)\left(p4(i,f,k,s) - \sum_{t \in C4(i,f,k)} S4(i,f,k,t) * p4(i,f,k,t) \right) \\ &- \sigma4(i,f,k)\left(a4(i,f,k,s) - \sum_{t \in C4(i,f,k)} S4(i,f,k,t) * a4(i,f,k,t) \right) \\ &\text{for } i = 1,\dots,C1; f = 1,\dots,C2(i); k = 1,\dots,C3(i,f); s = 1,\dots,C4(i,f,k) \end{aligned} \tag{7b}$$

Assume $\sigma1=0$. This assumption is valid in USAGE-Food. Using this assumption, we now substitute from (1b) – (6b) into (7b) to obtain

$$\begin{aligned} & x4(i,f,k,s) - a4(i,f,k,s) = x0 \\ & - \sigma2(i)\left(\begin{array}{l} \sum_{j \in C3(i,f)} S3(i,f,j) * \left[\sum_{ss \in C4(i,f,j)} S4(i,f,j,ss) * p4(i,f,j,ss) + \sum_{ss \in C4(i,f,j)} S4(i,f,j,ss) * a4(i,f,j,ss) \right] \\ - \sum_{t \in C2(i)} S2(i,t) * \sum_{j \in C3(i,t)} S3(i,t,j) * \left[\sum_{ss \in C4(i,t,j)} S4(i,t,j,ss) * p4(i,t,j,ss) + \sum_{ss \in C4(i,t,j)} S4(i,t,j,ss) * a4(i,t,j,ss) \right] \end{array} \right) \\ & - \sigma3(i,f)\left(\begin{array}{l} \sum_{ss \in C4(i,f,k)} S4(i,f,k,ss) * p4(i,f,k,ss) + \sum_{ss \in C4(i,f,k)} S4(i,f,k,ss) * a4(i,f,k,ss) \\ - \sum_{t \in C3(i,f)} S3(i,f,t) * \left[\sum_{ss \in C4(i,f,t)} S4(i,f,t,ss) * p4(i,f,t,ss) + \sum_{ss \in C4(i,f,t)} S4(i,f,t,ss) * a4(i,f,t,ss) \right] \end{array} \right) \\ & - \sigma4(i,f,k)\left(\begin{array}{l} p4(i,f,k,s) + a4(i,f,k,s) \\ - \left[\sum_{t \in C4(i,f,k)} S4(i,f,k,t) * p4(i,f,k,t) + \sum_{t \in C4(i,f,k)} S4(i,f,k,t) * a4(i,f,k,t) \right] \end{array} \right) \\ & \text{for } i = 1,\dots,C1; f = 1,\dots,C2(i); k = 1,\dots,C3(i,f); s = 1,\dots,C4(i,f,k) \end{aligned} \tag{8}$$

Equation (8) expresses percentage changes in demands for inputs at the lowest level as functions of percentage changes in industry input requirements [x0] and lowest-level price and technical variables [p4(i,f,k,s) and a4(i,f,k,s)].

4-level nesting for production functions in USAGE-Food

Figure A3.1 indicates the nesting structure in the production function for an industry in USAGE-Food. Table A3.1 records how many items appear in each nest.

X0 is total input for the industry.

Total input is created by a combination of 2 items at level 1. These two items are Genuine inputs and Other costs, denoted by X1(1) and X1(2). Thus, C1 = 2, see Table A3.1. This is the number of items at level 1 that go to make up total input.

Because there are two items at level 1 there must be 2 nests at level 2. In USAGE-Food, the first nest at level 2, that is the nest that creates the first item at level 1, contains C2(1) items. These items are: Primary factor, denoted by X2(1,1); Composite food, denoted by X2(1,2); and C2(1) -2 other intermediate inputs, denoted by X2(1,3), ..., X2(1,C2(1)). The second nest at level 2 contains just one item [C2(2) = 1]. This is simply Other costs repeated from level 1 but now denoted by X2(2,1), that is the quantity of the first (and only) input at level 2 that makes up the second input at level 1.

Because there are C2(1)+C2(2) items at level 2 there must be C2(1)+C2(2) nests at level 3 and because C2(2) = 1, Figure A3.1 shows C2(1)+1 nests at level 3. In USAGE-Food, the first nest at level 3, that is the nest that creates the first item [X2(1,1)] at level 2, contains three items [that is C3(1,1) =3]. These items are the constituents of Primary factors, namely labor, capital and land, denoted by X3(1,1,1), ..., X3(1,1,C3(1,1)). The second nest at level 3, that is the nest that creates the second item [X2(1,2)] at level 2 contains 26 items [C3(1,2) = 26]. The 26 items are categories of Food identified in the USAGE input-output data (see Table 1.1)[9]. The remaining nests at level 3 each contain only one item, which is simply a renamed item from level 2. Hence, C3(1,k)= 1 for k = 3, 4, … C2(1) and C3(2,1)=1.

Because there are $C3(1,1) + C3(1,2) + \sum_{k=3}^{C2(1)} C3(1,k) + C3(2,1)$ items at level 3 there must be the same number of nests at level 4. The first C3(1,1) of these nests each contain just one item. The item in the first of these nests is Labor renamed as X4(1,1,1,1). The item in the second nest is Capital, renamed as X4(1,1,2,1). The item in the C3(1,1) nest, that is the third nest, is Land, renamed as X4(1,1,3,1). In our notation, C4(1,1,k) = 1 for k = 1, …C3(1,1).

The next C3(1,2) nests at level 4 each contain 2 items. In each nest, the two items are the domestic and imported versions of a Food item (e.g. Flour) identified at level 3.

In our notation, C4(1,2,k) = 2 for all k = 1, , …C3(1,2).

The next $\sum_{k=3}^{C2(1)} C3(1,k)$ nests at level 4 each contain 2 items. In each nest, the two items are the domestic and imported versions of a non-food commodity (e.g. Iron ore) identified at level 3.

In our notation, C4(1,f,1) = 2 for all f = 3, …C2(1).

The last nest [C3(2,1)=1] at level 4 contains one item [C4(2,1,1)= 1] which is Other costs, yet again renamed, this time as X4(2,1,1,1).

[9] As indicated in footnote 3 to Table 1.1, in one of our simulations the food nest contains only 11 items.

Figure A3.1. Nesting assumptions for an industry production function in USAGE-Food

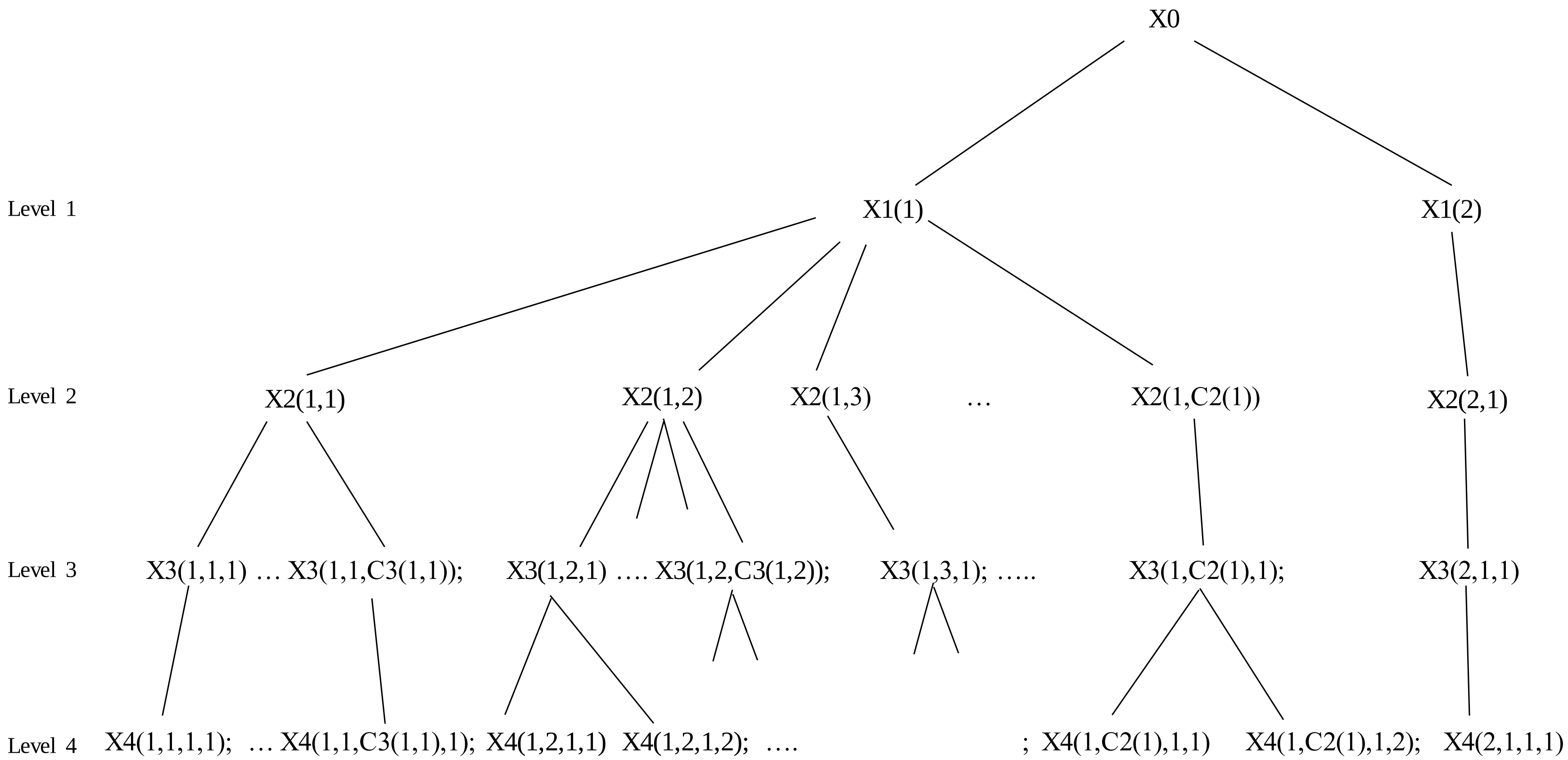

Table A3.1. Number of items in the production function nests in USAGE-Food

Level 1	C1=2					
Level 2	C2(1)=368[a)]	C2(2)=1				
Level 3	C3(1,1) = 3[(c)]	C3(1,2)=26[(b)]	C3(1,3)=1	…	C3(1,368)=1	C3(2,1)=1
Level 4	C4(1,1,k)=1 for k= 1, 2, 3	C4(1,2,k)=2 For k = 1, , 26	C4(1,f,1)=2 for f = 3, ..,C2(1)	C4(2,1,1) = 1		

[(a)] USAGE-Food identifies 392 commodities at the input-output level (see Table A2.1). Of these, 26 are food items (see Table 1.1). Thus, there are 367 commodity inputs at level 2, 366 commodities defined at the input-output level plus Food. These commodity inputs feed into the Genuine input X1(1). The composite primary factor input also appears in the level 2 nest that makes the composite Genuine input. Thus, C2(1) = 368.

[(b)] There are 26 food items at the input-output level. These are combined in a level 3 nest to form composite Food [X2(1,2)] which appears in level 2. Thus, C3(1,1) = 26.

[(c)] There are three primary factors that combine at level 3 to form the composite Primary factor at level 2 [X2(1,1)].

Now we consider how (8) simplifies in USAGE-Food, taking account of the number of items in each nest. Our aim is to derive equations for each of the level-4 inputs that justify the GEMPACK equations that appear in the computer representation of USAGE-Food.

Other costs: x4(2,1,1,1)

$$
\begin{aligned}
& x4(2,1,1,1) - a4(2,1,1,1) = x0 \\
& -\sigma 2(2)\left(\begin{aligned} & \sum_{j\in C3(2,1)} S3(2,1,j)*\left[\sum_{ss\in C4(2,1,j)} S4(2,1,j,ss)*p4(2,1,j,ss) + \sum_{ss\in C4(2,1,j)} S4(2,1,j,ss)*a4(2,1,j,ss)\right] \\ & -\sum_{t\in C2(2)} S2(2,t)*\sum_{j\in C3(2,t)} S3(2,t,j)*\left[\sum_{ss\in C4(2,t,j)} S4(2,t,j,ss)*p4(2,t,j,ss) + \sum_{ss\in C4(2,t,j)} S4(2,t,j,ss)*a4(2,t,j,ss)\right]\end{aligned}\right) \\
& -\sigma 3(2,1)\left(\begin{aligned} & \sum_{ss\in C4(2,1,k)} S4(2,1,k,ss)*p4(2,1,,k,ss) + \sum_{ss\in C4(2,1,,k)} S4(2,1,,k,ss)*a4(2,1,,k,ss) \\ & -\sum_{t\in C3(2,1)} S3(2,1,t)*\left[\sum_{ss\in C4(2,1,t)} S4(2,1,t,ss)*p4(2,1,t,ss) + \sum_{ss\in C4(2,1,t)} S4(2,1,t,ss)*a4(2,1,t,ss)\right]\end{aligned}\right) \\
& -\sigma 4(2,1,1)\left(\begin{aligned} & p4(2,1,1,s) + a4(2,1,1,s) \\ & -\left[\sum_{t\in C4(2,1,1)} S4(2,1,1,t)*p4(2,1,1,t) + \sum_{t\in C4(2,1,1)} S4(2,1,1,t)*a4(2,1,1,t)\right]\end{aligned}\right)
\end{aligned}
\tag{9}
$$

Referring to Table A1 we see that:

C3(2,1)= 1 Hence S3(2,1,1)=1

C4(2,1,1)=1 Hence S4(2,1,1,1)=1

C2(2)=1 Hence S2(2,1)=1

Consistent with the GEMPACK code, (9) implies that

$$x4(2,1,1,1) - a4(2,1,1,1) = x0 \tag{10}$$

Primary factors: x4(1,1,1,1), x1(1,1,2,1) and X(1,1,3,1)

C3(1,1)= 3

C4(1,1,k)=1 for k = 1, 2, 3 Hence S4(1,1,k,1) = 1 for all k

C2(1) =372

(8) simplifies to

$$x4(1,1,k,1) - a4(1,1,k,1) = x0$$
$$-\sigma 2(1)\left(\begin{array}{l} \sum_{j \in C3(1,1)} S3(1,1,j)*[p4(1,1,j,1)+a4(1,1,j,1)] \\ - \sum_{t \in C2(1)} S2(1,t)* \sum_{j \in C3(1,t)} S3(1,t,j)*\left[\sum_{ss \in C4(1,t,j)} S4(1,t,j,ss)*p4(1,t,j,ss) + \sum_{ss \in C4(1,t,j)} S4(1,t,j,ss)*a4(1,t,j,ss) \right] \end{array} \right)$$
$$-\sigma 3(1,1)\left(\begin{array}{l} p4(1,1,k,1)+a4(1,1,k,1) \\ - \sum_{t \in C3(1,1)} S3(1,1,t)*[p4(1,1,t,1)+a4(1,1,t,1)] \end{array} \right)$$
$$\text{for } k = 1,\ldots,C3(1,1) \qquad (11)$$

Consistent with the GEMPACK code, this can be written as:

$$x4(1,1,k,1) - a4(1,1,k,1) = x0$$
$$-\sigma 2(1)\left(\begin{array}{l} p1prim + a1prim \\ -\{p1add + a1add\} \end{array} \right)$$
$$-\sigma 3(1,1)\left(\begin{array}{l} p1prim(k) + a1prim(k) \\ -[p1prim + a1prim] \end{array} \right) \qquad (12)$$
$$\text{for } k = 1,\ldots,C3(1,1)$$

where

$p1prim = \sum_{j \in C3(1,1)} S3(1,1,j)*[p4(1,1,j,1)]$, that is p1prim is the price of composite primary factor

$p1prim(k) = p4(1,1,k,1)$, that is p1prim(k) is the price of primary factor k

$p1add = \sum_{t \in C2(1)} S2(1,t)* \sum_{j \in C3(1,t)} S3(1,t,j)* \sum_{ss \in C4(1,t,j)} S4(1,t,j,ss)*p4(1,t,j,ss)$ is the price of composite genuine inputs.

$a1prim = \sum_{j \in C3(1,1)} S3(1,1,j)*[a4(1,1,j,1)]$, that is a1prim is total primary-factor-saving technical change in an industry

$a1prim(k) = a4(1,1,k,1)$, that is a1prim(k) is primary-factor-k-saving technical change in an industry r and

$a1add = \sum_{t \in C2(1)} S2(1,t)* \sum_{j \in C3(1,t)} S3(1,t,j)* \sum_{ss \in C4(1,t,j)} S4(1,t,j,ss)*a4(1,t,j,ss)$, that is a1add is total genuine-input-saving technical change in an industry.

Food items: x4(1,2,k,s), for k= 1, …, C3(1,2) and s= 1, 2

C3(1,2) =26

C4(1,2,j)=2

C2(1)= 368

$$
\begin{aligned}
& x4(1,2,k,s) - a4(1,2,k,s) = x0 \\
& -\sigma 2(1)\left(\begin{aligned}&\sum_{j\in C3(1,2)} S3(1,2,j)*\left[\sum_{ss\in C4(1,2,j)} S4(1,2,j,ss)*p4(1,2,j,ss)+\sum_{ss\in C4(1,2,j)} S4(1,2,j,ss)*a4(1,2j,ss)\right]\\ &-\sum_{t\in C2(1)} S2(1,t)*\sum_{j\in C3(1,t)} S3(1,t,j)*\left[\sum_{ss\in C4(1,t,j)} S4(1,t,j,ss)*p4(1,t,j,ss)+\sum_{ss\in C4(1,t,j)} S4(1,t,j,ss)*a4(1,t,j,ss)\right]\end{aligned}\right) \\
& -\sigma 3(1,2)\left(\begin{aligned}&\sum_{ss\in C4(1,2,k)} S4(1,2,k,ss)*p4(1,2,k,ss)+\sum_{ss\in C4(1,2,k)} S4(1,2,k,ss)*a4(1,2,k,ss)\\ &-\sum_{t\in C3(1,2)} S3(1,2,t)*\left[\sum_{ss\in C4(1,2,t)} S4(1,2,t,ss)*p4(1,2,t,ss)+\sum_{ss\in C4(1,2,t)} S4(1,2,t,ss)*a4(1,2,t,ss)\right]\end{aligned}\right) \\
& -\sigma 4(1,2,k)\left(\begin{aligned}&p4(1,2,k,s)+a4(1,2,k,s)\\ &-\left\{\sum_{t\in C4(1,2,k)} S4(1,2,k,t)*p4(1,2,k,t)+\sum_{t\in C4(1,2,k)} S4(1,2,k,t)*a4(1,2,k,t)\right\}\end{aligned}\right) \\
& \qquad\qquad \text{for } k=1,\ldots,C3(1,2);\ s=1,\ldots,C4(1,2,k)
\end{aligned}
\tag{13}
$$

Consistent with the GEMPACK code, this can be re-written as:

$$
\begin{aligned}
& x4(1,2,k,s) - a4(1,2,k,s) = x0 \\
& \quad -\sigma 2(1)\left(\begin{aligned}&pfood+afood\\ &-\{p1add+a1add\}\end{aligned}\right) \\
& \quad -\sigma 3(1,2)\left(\begin{aligned}&pfood(k)+afood(k)\\ &-\{pfood+afood\}\end{aligned}\right) \\
& \quad -\sigma 4(1,2,k)\left(\begin{aligned}&pfood(k,s)+afood(k,s)\\ &-\{pfood(k)+afood(k)\}\end{aligned}\right) \\
& \qquad\qquad \text{for } k=1,\ldots,C3(1,2);\ s=1,\ldots,C4(1,2,k)
\end{aligned}
\tag{14}
$$

where

$$pfood = \sum_{j\in C3(1,2)} S3(1,2,j)*\sum_{ss\in C4(1,2,j)} S4(1,2,j,ss)*p4(1,2,j,ss)$$

$$pfood(k) = \sum_{ss\in C4(1,2,k)} S4(1,2,k,ss)*p4(1,2,k,ss)$$

$$pfood(k,s) = p4(1,2,k,s)$$

$$p1add = \sum_{t\in C2(1)} S2(1,t)*\sum_{j\in C3(1,t)} S3(1,t,j)*\sum_{ss\in C4(1,t,j)} S4(1,t,j,ss)*p4(1,t,j,ss)$$

$$afood = \sum_{j\in C3(1,2)} S3(1,2,j)*\sum_{ss\in C4(1,2,j)} S4(1,2,j,ss)*a4(1,2,j,ss)$$

$$afood(k) = \sum_{ss\in C4(1,2,k)} S4(1,2,k,ss)*a4(1,2,k,ss)$$

$afood(k,s) = a4(1,2,k,s)$ and

$$a1add = \sum_{t\in C2(1)} S2(1,t)*\sum_{j\in C3(1,t)} S3(1,t,j)*\sum_{ss\in C4(1,t,j)} S4(1,t,j,ss)*a4(1,t,j,ss)$$

Non-Food intermediate input items: x4(1,f,1,s) for f = 3, … C2(1) and s= 1, 2

C3(1,f) =1 Hence S3(1,f,1)= 1 for all relevant f

C4(1,f,1)=2 for all relevant f

C2(1)= 368

$$
\begin{aligned}
&x4(1,f,1,s) - a4(1,f,1,s) = x0 \\
&-\sigma 2(1)\left(\begin{array}{l}\left[\sum_{ss\in C4(1,f,1)} S4(1,f,1,ss)*p4(1,f,1,ss) + \sum_{ss\in C4(1,f,1)} S4(1,f,1,ss)*a4(1,f,1,ss)\right] \\ -\sum_{t\in C2(1)} S2(1,t)*\sum_{j\in C3(i,t)} S3(1,t,j)*\left[\sum_{ss\in C4(1,t,j)} S4(1,t,j,ss)*p4(1,t,j,ss) + \sum_{ss\in C4(1,t,j)} S4(1,t,j,ss)*a4(1,t,j,ss)\right]\end{array}\right) \\
&-\sigma 4(1,f,1)\left(\begin{array}{l} p4(1,f,1,s) + a4(1,f,1,s) \\ -\left\{\sum_{t\in C4(1,f,1)} S4(1,f,1,t)*p4(1,f,1,t) + \sum_{t\in C4(1,f,1)} S4(1,f,1,t)*a4(1,f,1,t)\right\}\end{array}\right) \\
&\qquad \text{for } f = 3,\ldots,C2(1); s = 1,\ldots,C4(1,f,1)
\end{aligned}
\tag{15}
$$

Consistent with the GEMPACK code, this can be written as

$$
\begin{aligned}
&x4(1,f,1,s) - a4(1,f,1,s) = x0 \\
&\quad -\sigma 2(1)\left(\begin{array}{l} pnonfood(f) + anonfood(f) \\ -\{padd + add\}\end{array}\right) \\
&\quad -\sigma 4(1,f,1)\left(\begin{array}{l} pnonfood(f,s) + anonfood(f,s) \\ -\{pnonfood(f) + anonfood(f)\}\end{array}\right) \\
&\qquad \text{for } f = 3,\ldots,C2(1); s = 1,\ldots,C4(1,f,1)
\end{aligned}
\tag{16}
$$

where

$$pnonfood(f) = \sum_{ss\in C4(1,f,1)} S4(1,f,1,ss)*p4(1,f,1,ss)$$

$$padd = \sum_{t\in C2(i)} S2(1,t)*\sum_{j\in C3(i,t)} S3(1,t,j)*\sum_{ss\in C4(i,t,j)} S4(1,t,j,ss)*p4(1,t,j,ss)$$

$$pnonfood(f,s) = p4(1,f,1,s)$$

$$anonfood(f) = \sum_{ss\in C4(1,f,1)} S4(1,f,1,ss)*a4(1,f,1,ss)$$

$a1add = \sum_{t\in C2(1)} S2(1,t)*\sum_{j\in C3(1,t)} S3(1,t,j)*\sum_{ss\in C4(1,t,j)} S4(1,t,j,ss)*a4(1,t,j,ss)$, and

$$anonfood(f,s) = a4(1,f,1,s)$$

Utility function: Stone-Geary with 3 level nest

In USAGE-Food we specify utility via 3 nests with a Stone-Geary function at the top level:

$$U = \sum_i B(i)*\ln\left(\frac{X1(i)}{Q} - G(i)\right) \tag{L1U}$$

$$X1(i) = CES2\left(\frac{X2(i,f)}{A2(i,f)} \quad f = 1,\ldots,C2(i)\right) \text{ for i = 1, ..., C1} \tag{L2U}$$

$$X2(i,f) = CES3\left(\frac{X3(i,f,k)}{A3(i,f,k)} \quad k = 1,...,C3(i,f)\right) \text{ for i = 1, ..., C1 and f = 1, ..., C2(i)} \quad (L3U)$$

where

Q is number of households,;

B(i) is the marginal budget share for commodity i;

G(i) is the household per capita subsistence requirement of commodity i;

X1(i) is total household consumption of level-1 commodity i;

X2(i,f) is total household consumption of level-2 commodity i,f, the f^{th} commodity in the nest that generates level-1 commodity i; and

X3(i,f,k) is total household consumption of level-3 commodity i,f,k, the k^{th} commodity in the nest that generates level-2 commodity i,f; and

the A's are preference-change variables.

Figure A3.2 indicates the particular nesting structure in USAGE-Food. U is total utility specified by L(1). Total utility is created by a combination of 367 items at level 1. These are per household consumption of 366 non-food input-output commodities denoted by X1(1) to X1(366), and composite food denoted by X1(367). Thus, C1 = 367. This is the number of items at level 1 that go to make up total utility.

Because there are 367 items at level 1 there must be 367 nests at level 2. In USAGE-Food, the first 366 nests at level 2, that is the nests that create the first 366 items at level 1 each contain a single item denoted by X2(i,1), i = 1, …, 366. Thus, C2(i) =1 for all i = 1, …, 366. The last nest at level 2 contains the 26 input-output food items. Thus C2(367) = 26.

Because there are 392 items at level 2, Figure A3.2 shows 392 nests at level 3. Each of these nests has two items. The two items are the domestic and imported versions of the level-2 input-output commodity.

Optimization of level-1: cost minimization subject to Stone-Geary utility constraint

For any given level of utility U, households

choose X1(1), …, X1(C1)

to minimize $\sum_i P1(i) * X1(i)$

subject to $U = \sum_i B(i) * \ln\left(\frac{X1(i)}{Q} - G(i)\right)$

First order conditions:

$$P1(i) = \Lambda * B(i) * \frac{1/Q}{X1(i)/Q - G(i)} \quad (17)$$

where Λ is the Lagrangian multiplier.

Rearrange (17) as

$$P1(i) * \left[X1(i)/Q - G(i)\right] = \frac{\Lambda * B(i)}{Q} \quad (18)$$

Sum over i

$$\frac{Y}{Q} - \sum_i P1(i) * G(i) = \frac{\Lambda}{Q} \quad (19)$$

where Y = $\sum_i P1(i) * X1(i)$, that is Y is the household budget.

Substitute (19) into (18). This gives the well known linear expenditure system:

$$\frac{X1(i)}{Q} = G(i) + \frac{B(i)}{P1(i)} * \left[\frac{Y}{Q} - \sum_j P1(j) * G(j) \right] \tag{20}$$

In percentage change form (20) can be written as

$$\frac{X1(i)}{Q} * \left(x1(i) - q \right) = 100 * dG(i) + \frac{B(i)}{P1(i)} * \frac{Y}{Q} * \left(\beta(i) + y - p1(i) - q \right)$$
$$- \left\{ \frac{B(i)}{P1(i)} * \sum_j P1(j) * G(j) \right\} * \left(\beta(i) - p1(i) \right) - \frac{B(i)}{P1(i)} * \left\{ \sum_j P1(j) * G(j) * \left[p1(j) \right] + 100 * \sum_j P1(j) * dG(j) \right\} \tag{21}$$

where variables denoted by lowercase symbols are percentage changes in variables denoted by the corresponding uppercase symbols. Notice that we use the change form, dG(i), for G(i). This is because G(i) can be of either sign and may move through zero.

After a considerable amount of tedious but elementary algebra we find that (21) can be rewritten as

$$\left(x1(i) - q \right) = \varepsilon(i) * \left(y - q \right) + \sum_j \eta(i,j) * p1(j)$$
$$+100 * Q * dG(i) / X1(i) - \varepsilon(i) * 100 * \sum_j S1(j) * Q * dG(j) / X1(j) - \varepsilon(i) \frac{1}{F} * \beta(i) \tag{22}$$

where $S1(i) = \frac{P1(i) X1(i)}{Y}$ (23)

$$F = \frac{-Y / Q}{Y / Q - \sum_j P1(j) * G(j)} \tag{24}$$

$\varepsilon(i) = \frac{B(i)}{S1(i)}$ and (25)

$$\eta(i,j) = KD(i,j) * \frac{\varepsilon(i)}{F} - \varepsilon(i) * S1(j) * \left(1 + \frac{\varepsilon(j)}{F} \right) \tag{26}$$

S1(i) is the share of i in household expenditure.

F is the negative of the reciprocal of the share of supernumerary expenditure in household expenditure. F is known as the Frisch coefficient.

$\eta(i,j)$ is the elasticity of household demand for commodity i with respect to a change in the price of commodity j.

$\varepsilon(i)$ is the expenditure elasticity of household demand for commodity i.

Preference variables

Equation (22) contains two preference-change variables for each of the C1 commodities at level 1. These can be written as $Q * dG(j) / X1(j)$ and $\beta(j)$. In effect, we reduce this to C1 preference changes by connecting $Q*dG(i)/X1(i)$ and $\beta(i)$ via C1 new variables a1com(i). We do this by writing:

$$\beta(i) = a1com(i) - \sum_k B(k)*a1com(k) \tag{27}$$

and

$$Q*dG(i)/X1(i) = 0.01\left(1+\frac{\varepsilon(i)}{F}\right)*\left[a1com(i) - \sum_k S1(k)*a1com(k)\right] \tag{28}$$

If we set a1com(i) at -1, then via (27) and (28) we are imposing a taste change against commodity i of about 1 per cent by reducing both the subsistence and supernumerary consumption of i by about 1 per cent. Not surprisingly as demonstrated below, under (27) and (28), (22) reduces to

$$\left(x1(i) - q\right) = \varepsilon(i)*\left(y-q\right) + \sum_j \eta(i,j)*p1(j) + a1com(i)) - \sum_k S1(k)*a1com(k) \tag{29}$$

To demonstrate (29), we start by substituting from (27) and (28) into (22) to obtain

$$\begin{aligned}\left(x1(i) - q\right) &= \varepsilon(i)*\left(y-q\right) + \sum_j \eta(i,j)*p1(j) \\ &+\left(1+\frac{\varepsilon(i)}{F}\right)*\left[a1com(i) - \sum_k S1(k)*a1com(k)\right] \\ &-\varepsilon(i)*\sum_j S1(j)*\left(1+\frac{\varepsilon(j)}{F}\right)*\left[a1com(j) - \sum_k S1(k)*a1com(k)\right] \\ &-\varepsilon(i)\frac{1}{F}*\left(a1com(i) - \sum_k B(k)*a1com(k)\right)\end{aligned} \tag{30}$$

We rewrite (30) with all of the preference expressions broken into individual terms:

$$\begin{aligned}\left(x1(i) - q\right) &= \varepsilon(i)*\left(y-q\right) + \sum_j \eta(i,j)*p1(j) \\ &+a1com(i) + \frac{\varepsilon(i)}{F}*a1com(i) - \sum_k S1(k)*a1com(k) - \frac{\varepsilon(i)}{F}*\sum_k S1(k)*a1com(k) \\ &-\varepsilon(i)*\sum_j S1(j)*a1com(j) - \varepsilon(i)*\sum_j S1(j)*\frac{\varepsilon(j)}{F}*a1com(j) \\ &-\varepsilon(i)*\sum_j S1(j)*\sum_k S1(k)*a1com(k) + \varepsilon(i)*\sum_j S1(j)*\frac{\varepsilon(j)}{F}*\sum_k S1(k)*a1com(k) \\ &-\varepsilon(i)*\frac{1}{F}*a1com(i) + \varepsilon(i)*\frac{1}{F}*\sum_k B(k)*a1com(k)\end{aligned} \tag{31}$$

Then we apply three identities: equation (25); sum of shares equal 1; and the share-weighted sum of expenditure elasticities equals 1. This yields (29).

Consumer demand functions in percentage change form

The complete 3-nest household demand system in percentage change form, similar to the GEMPACK specification in USAGE-Food, is:

$$x1(i) - q = \varepsilon(i)*\left(c-q\right) + \sum_j \eta(i,j)*p1(j) + a1com(i) - ave\_a1com \quad \text{for } i = 1, 2, \ldots, C1 \tag{32}$$

$$ave\_a1com = \sum_{k} S1(k) * a1com(k) \quad , \tag{33}$$

$$p1(j) = \sum_{f \in C2(j)} S2(j,f) * p2(j,f) + \sum_{f \in C2(j)} S2(j,f) * a2(j,f) \quad \text{for } j = 1,...,C1 \tag{34}$$

$$\begin{aligned} x2(i,f) - a2(i,f) = x1(i) - \sigma 2(i)\left(p2(i,f) - \sum_{t \in C2(i)} S2(i,t) * p2(i,t) \right) \\ - \sigma 2(i)\left(a2(i,f) - \sum_{t \in C2(i)} S2(i,t) * a2(i,t) \right) \\ \text{for } i = 1,...,C1; f = 1,...,C2(i) \end{aligned} \tag{35}$$

$$\begin{aligned} p2(i,f) = \sum_{k \in C3(i,f)} S3(i,f,k) * p3(i,f,k) + \sum_{k \in C3(i,f)} S3(i,f,k) * a3(i,f,k) \\ \text{for } i = 1,...,C1; \; f = 1,...,C2(i); \end{aligned} \tag{36}$$

and

$$\begin{aligned} x3(i,f,s) - a3(i,f,s) = x2(i,f) - \sigma 3(i,f)\left(p3(i,f,s) - \sum_{t \in C3(i,f)} S3(i,f,t) * p3(i,f,t) \right) \\ - \sigma 3(i,f)\left(a3(i,f,s) - \sum_{t \in C3(i,f)} S3(i,f,t) * a3(i,f,t) \right) \\ \text{for } i = 1,...,C1; f = 1,...,C2(i); s = 1,2 \end{aligned} \tag{37}$$

Equations (32) and (33) are a rewritten version of equation (29). Equations (34) and (35) follow from cost minimizing at the second level. Equations (36) and (37) follow from cost minimizing at the third level.

Figure A3.2. Nesting assumptions for consumer utility in USAGE-Food