Some Economic Benefits and Costs of Vegetarianism

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It is now fashionable in many circles to advocate vegetarianism, and many activist groups are vocal in their aim to convert the human race to vegetarians. What would be the economic costs and benefits of a shift away from meat consumption? In this article we provide some partial answers to this question. In three separate analyses we show (i) that it is much more costly to produce energy and protein from animal-based sources than from some plant-based sources, (ii) that sizable demand shifts away from meat consumption would result in significantly lower corn prices and production, and (iii) that the average U.S. consumer places a higher value on having meat in his or her diet than having any other food group. This information should help move forward our understanding of the economics of vegetarianism and provide an objective stance from which to evaluate the claims being made by advocates of vegetarianism.

Key Words: cost of nutrients, crop production, dietary costs, livestock production, value of meat, vegan, vegetarian

In her bestselling book *Food in History*, Reay Tannahill begins, "For 12,000 years there has been a steady undercurrent of antagonism between vegetarians and meat-eaters" (Tannahill 1988, p. 1). In the Old Testament—a sacred text shared by Judaism, Christianity, and to some extent Islam—humans began in the Garden of Eden, where "to every beast of the earth, and to every fowl of the air, and to everything that creepeth upon the earth, wherein there is life, I have given every green herb" (Genesis 1:30). The interpretation of this text to some scholars is clear: "this should be interpreted to mean: every green herb and *nothing else*" (Soler 1996, p. 52).

Yet humans left the Garden of Eden, and along with it, their herbivore diet. The natural history of humans, including archaeological evidence, suggests that *Homo sapiens* have always eaten both plants and animals (Tannahill 1988). For the vast majority of their existence, obtaining nutritional needs was a daily challenge for humans, and famine was a recurring threat. Given the scarcity of nutritional resources, it would seem odd for humans to restrict their diet for religious or cultural reasons, but that is exactly what they did. For example, as early as the sixth century B.C., Pythagoras and his followers led a vegetarian life (Spencer 2000). Because of religious beliefs, many cultures have restricted their consumption of animal products in different ways.

Reverence for the Old Testament caused some Jews to view vegetarianism as closer to the ideal life that God planned in the Garden of Eden. For this reason, Jews prefer to eat meat only from animals that are vegetarians, and thus ban the eating of pigs, which are omnivores. During the Middle Ages, meat was seen as a sign of earthly strength and power. Nobles who behaved poorly and were thus deemed unworthy of their power were punished by prohibiting the eating of meat, sometimes for life. The Catholic Church urged its congregation to seek spirituality and shun the pursuit of earthly power. To abstain from meat was to announce a preference for the spiritual world over the earthly world. Hence, the Catholic Church banned the eating of meat on Wednesdays, Saturdays, and all the days of Lent. Depending on how the ban was enforced, these days of meat-fasting could comprise half the days of the year (Montanari 1996, Tannahill 1988).

Eastern religions such as Hinduism, Buddhism, and Jainism maintain a belief in reincarnation, and a specific belief that humans can be reincarnated as livestock and vice versa. For these adherents, eating an animal can mean eating an an-

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cestor, so it is not surprising that vegetarianism is more popular in the regions where these religions took hold. Ancient India became heavily reliant on dairy products from female cows and the labor from male cows, and urged against the killing of cows because the animals were generally worth more alive than dead. Combined with the idea of reincarnation, the Hindu Sacred Cow emerged (Tannahill 1988). Similar beliefs existed in ancient Egypt, and like some Catholic priests, many of the Egyptian priests also abstained from meat (Spencer 2000). Pockets of vegetarianism also existed in American and European cultures, such as the experimental vegetarian commune that settled on the Kansas frontier shortly before the Civil War (Gambone 1972), but they were unusual.

Vegetarianism can denote a specific diet, or be used as an umbrella term for a variety of diets that restrict consumption of animal products. When used to denote a specific diet, the term "vegetarian" refers to the abstaining from all meat, fish, or shellfish, but does include eggs and dairy products in the diet. A "pescatarian" shuns the eating of all animal flesh except fish, and a "vegan" excludes any product derived from animals; dairy, eggs, and even gelatin are not part of a vegan diet. This paper largely concerns vegetarianism, as it focuses on the consequences of changes in meat consumption, but some of the empirical results also consider dairy and eggs, which are pertinent to vegan diets.

A number of recent cultural and technological changes have made vegetarianism a timely topic in the Western and Eastern worlds alike. Livestock production technologies, such as improved feed formulations, have made it cheaper to raise chickens and hogs indoors exclusively. For egg-laying hens and swine, these facilities confine the animal to cages or pens barely larger than the animal itself. Gestating sows are confined to stalls so small that they prohibit the animal from turning around, and laying hens are allotted 67 square inches of space at most, despite the fact that the hen needs 75 square inches to stand comfortably and 144 square inches to spread its wings (Dawkins and Hardie 1989, United Egg Producers 2008, Mason and Singer 1990, Singer 2001, Singer and Mason 2006). Opponents of such practices refer to these facilities as factory farms, and, beginning with Ruth Harrison's book *Animal Machines* (Harrison 1964), have opposed such farms and urged consumers to abstain from animal products. For example, Singer (2001, p. 177) states, "The most urgent task of the Animal Liberation movement is to persuade as many people as possible to make this commitment [to stop eating meat], so that the boycott will spread and gain attention."

Opposition to factory farming is becoming more prominent and has led to more than just propaganda. In Arizona, California, and Florida, it is now illegal for farmers to confine hogs to small crates (Arnot and Gauldin 2006). Egg producers have been persuaded to increase the size of hen cages (Smith 2007), Burger King has begun buying eggs from cage-free production systems (Martin 2007), and retailers such as Whole Foods have created an animal-compassionate label for its meat products (Martin 2006). As consumers become more aware of modern farming practices, vegetarianism may rise. When the president of Jewish Vegetarians of North America was asked the major reason children adopt vegetarianism, he responded, "Compassion for animals is the major, major reason" (Stobbe 2009).

However, it would be a mistake to attribute vegetarianism to animal welfare concerns solely, or to any one single concern. In the United States, modern vegetarianism arose largely from the counterculture movement of the mid-1960s and a cultural movement that seeks "pure" food that is removed from animal production, less processed, generally less affected by scientific advancements, and sometimes associated with New Age spirituality (Spencer 2000). Health concerns are a major reason for vegetarianism, especially for those concerned with cholesterol. Although a healthy diet can certainly include meat, there is increasing evidence that a vegetarian diet may be healthier (Sabate 2003).

As the environment has become an increasingly important policy issue, some individuals see vegetarianism as a way to personally combat agricultural pollution (Spencer 2000, Stuart 2006). Livestock production is often seen as a food factory in reverse, consuming more energy than it produces. Opponents of "factory farms" contend that such operations represent inefficient methods of food production. Moreover, activists often consider calories fed to animals as "wasted" in that they represent calories that could have been used to feed hungry humans. The argument is that by converting to vegetarianism, there would be fewer crop acres planted and hence less pollution from fertilizer runoff and pesticides. Furthermore, a portion of the acres no longer needed to feed Americans could be used to feed less fortunate parts of the world (Singer and Mason 2006). By ignoring the fact that this “reverse-protein factory” creates form utility (i.e., some people prefer eating meat to raw corn), vegetarian advocates argue that meat production is inefficient and unethical. However, meat-eaters would contend that the loss in calories is acceptable given the increase in eating satisfaction that results from turning corn into steak.

Identifying which concern (animal welfare, religion, health, or the environment) is the main driver of vegetarianism is difficult, and probably the wrong question to ask. Perhaps a question more amenable to the tool-kit of economists is, what would be the economic effects of increasing vegetarianism? The number of vegetarians in the United States is small, representing only about 3 percent of the population (*Vegetarian Journal* 2003, Norwood, Lusk, and Prickett 2007, Stobbe 2009). However, as previously noted, advocates of vegetarianism have become more prominent and often make no attempt to hide their objective of converting the population to vegetarianism—whatever the means. Such claims are made in all seriousness, and as such, one should seriously evaluate their consequences.

Given the stated aim of the vegetarianism advocates and the increased acceptance of vegetarianism as a lifestyle choice, it is surprising that so little work on the economics of vegetarianism has been conducted. For example, a search for the word “vegetarian” in the database EconLit yielded only 5 peer-reviewed journal articles, and only one of these explicitly attempted to investigate the economic effects of vegetarianism. In the only paper on the issue, Risku-Norja and Maenpaa (2007) constructed an input-output model of the Finnish agricultural and food production system and forecasted that an increase in vegetarianism would reduce the need for agricultural land and lead to positive environmental outcomes such as lower greenhouse gas emissions. However, these authors also projected that greater vegetarianism would generally have negative economic consequences for the agricultural production sector.

The purpose of this article is to empirically study the economics of vegetarianism from several different angles. We do not claim to provide an exhaustive treatment of the issue. The goal is to move forward our understanding of the economics of vegetarianism and to provide an objective stance from which to evaluate the claims being made by many vegetarians. In the next section of this paper, we first tackle the issue of the relative cost of producing calories and protein from some plant-based and animal-based sources. This analysis is intended to provide insight into the economic efficiency of the present-day agricultural production system as compared to one in which food is produced only via plant-based agriculture.

Of course, simple comparisons of costs cannot fully reflect how crop prices and consumption will change if a large portion of the population decides to eschew meat consumption. Thus, in the third section, we study the interrelationship of corn and livestock markets and investigate the effect of a shift away from meat consumption on corn prices. Although the first two analyses provide insight into the economic efficiency of eating meat, people care about more than the efficiency with which food is produced. In particular, people care about which foods they eat and how they taste. Although many advocates of vegetarianism suggest that people can, over time, easily give up meat, it is an open question as to how much people value having meat in their diet. The penultimate section of this article seeks to determine the value that consumers place on maintaining their current level of meat consumption in their diet. The final section concludes.

Cost of Producing Nutrients

It is often argued that producing meat is inefficient. For example, Francione (2004, p. 116) argues that “respected environmental scientists have pointed out the tremendous inefficiencies and resulting costs to our planet of animal agriculture. For example, animals consume more protein than they produce. For every kilogram (2.2 pounds) of animal protein produced, animals consume an average of almost 6 kilograms…of plant protein from grains and forage.” Similar arguments can be found in Singer (2001). The economic question, however, is not necessarily the rate at which an organism converts raw inputs into nutrients suitable for human consumption, but rather the relative cost of producing nutrients from various sources.

To address this issue, we utilize data reported by the U.S. Department of Agriculture's Economic Research Service (ERS) regarding the cost of production for various agricultural commodities (USDA 2004 and 2005). As shown in Table 1, ERS estimates indicate that the average cost of producing corn was about $387/acre from 2004 to 2005, whereas the average cost of producing wheat was only about $197/acre over the same time period. The fourth column in Table 1 takes information on average crop yields over this time period to convert the cost from the units of acres planted to pounds produced. Of the four crops shown in Table 1, corn is the least expensive to produce on a per-pound basis, whereas peanuts are the most expensive to produce. The last four rows of Table 1 carry out similar calculations for livestock, poultry, and milk. The ERS reports cost-of-production data only for hogs and milk, so we gathered cost of production data on cattle from Lawrence (2005). The poultry sector is highly integrated, making detailed estimates of cost of production difficult to find. As such, we turned to Canadian budget data for 1999 produced by the Manitoba Chicken Producer Board (1999) for an estimate of the production costs for broilers, and used Georgia broiler prices to confirm the validity of this estimate (National Agricultural Statistics Service 2006).[1] The fourth column of Table 1 reports the estimated costs of farm production on a per pound basis, which factors in the dressing percentage for each animal species.

Results reveal that it is significantly more expensive to produce a pound of meat (or milk) than a pound of commodity crops. However, the nutritional contents of crops and livestock are not identical. To determine the nutritional content of each of the commodities listed in Table 1, the U.S. Department of Agriculture's Agricultural Research Service (ARS) National Nutrient Database was consulted (USDA 2006). The database contains detailed nutritional information for a wide variety of foods. For each commodity, we searched the database to find products that most closely resembled the raw, uncooked, unprocessed commodity, and collected information on two primary nutritional categories for each food type: energy and protein. For meat, this raw commodity was the carcass.

The fifth and sixth columns of Table 1 report the nutritional content of each commodity on a per pound basis. Peanuts contain more energy and soybeans contain more protein than any of the other commodities listed in Table 1. Meat products contain more protein than corn and wheat, but less protein than soybeans and peanuts. The last two columns in Table 1 report the ultimate statistic of interest: the cost per nutrient produced, which is obtained by dividing the cost of production by the nutrient content of each commodity. A comparison of the plant-based foods to the animal-based foods reveals that obtaining nutrients from plants is *much* cheaper than obtaining the same nutrients from meat or dairy products. Obtaining a kcal of energy from the cheapest meat product (broilers) is 5 times more costly than obtaining a kcal from the most expensive plant-based product (peanuts). A similar result is true for protein. Obtaining a gram of protein from the cheapest meat product (broilers) is 3.26 times more costly than obtaining a gram of protein from the most expensive plant-based product (peanuts). These cost differences are remarkable when one considers that suggested daily energy and protein intake is about 2,000 kcal and 100 grams, respectively.

Of course, these price differences reflect not just costs of production but also the utility that individuals receive in obtaining nutrients from various sources. It may be cheaper to obtain energy from corn than from cattle, but some people prefer eating beef to eating corn. That is, there are legitimate reasons why consumers choose to obtain nutrients from more expensive food sources. This is a topic we return to later in the paper; this section seeks only to analyze cost differences in nutrients, acknowledging that the eating experience differs by food source.

One important qualification regarding the results in Table 1 is in order. The costs of producing each of the nutrients are at the farm level. However, most agricultural commodities go through some form of processing before they arrive at the grocery store or restaurant. This processing, in addition to other expenses such as labor and transportation, increases the cost of each food item as the product moves from the processing to the wholesale and retail stage. If these costs differ

[1] We used the currency conversion that prevailed at the time the budget was published, which was UR$1 = Can$1.5.

Table 1. Cost of Producing Nutrients from Various Agricultural Commodities

	Production Costs[a]			Nutrient Content[b]		Cost per Nutrient Produced at the Farm Level	
Commodity	Cost of Production	Yield	Cost ($/lb)	Energy (kcal/lb)	Protein (grams/lb)	Cost of Energy ($/kcal)	Cost of Protein ($/gram)
CROPS							
Corn	$387.03 per acre	162.5 bushels per acre; 56 lbs per bushel	$0.043	80.526	2.078	$0.001	$0.020
Soybeans	$256.7 per acre	46 bushels per acre; 60 lbs per bushel	$0.093	98.397	8.050	$0.001	$0.012
Wheat	$196.68 per acre	38.1 bushels per acre; 60 lbs per bushel	$0.086	72.143	2.782	$0.001	$0.031
Peanuts	$638.88 per acre	3186.5 lbs per acre	$0.201	125.092	5.692	$0.002	$0.035
LIVESTOCK, POULTRY, AND MILK							
Hogs (farrow to finish)	$50.53 per cwt live weight gain	75.5 lbs of meat per live cwt	$0.669	82.953	3.069	$0.008	$0.218
Cattle (finishing one steer)	$917.87 per head live weight	1150 lbs per head; 0.65 lbs of meat per live lb	$1.228	64.200	3.821	$0.019	$0.321
Broilers	$0.33 per lb live weight	0.7 lbs meat per live lb	$0.471	47.433	4.104	$0.010	$0.115
Milk	$20.57 per cwt	100 lbs per cwt	$0.206	13.237	0.710	$0.016	$0.290

[a] Cost of production data for all commodities except cattle and broilers are from USDA-ERS Commodity Costs and Returns data (USDA 2004 and 2005) averaged across years 2004 and 2005. Production costs for cattle, averaged across years 2004 and 2005, are from Lawrence (2005). Production costs for broilers (converted from Canadian dollars to U.S. dollars) for year 1999 are from the Manitoba Chicken Producer Board (1999).

[b] All nutritional information was obtained from the USDA-ARS National Nutrient Database (USDA 2006). Nutritional information for livestock is based on the entire carcass.

for plant- and animal-based foods, the relative cost of obtaining nutrients from animals and plants at the retail level will be altered as well. In fact, it is the case that many plant-based foods undergo more transformation than animal-based foods. For example, wheat is processed into flour, which in turn is mixed with other ingredients and baked into bread, which is then packaged and shipped to the supermarket. By contrast, a steak or hamburger at the retail level has undergone relatively little transformation from the farm.

To account for these differences, Table 2 reports the farmer's share of the retail dollar reported by the ERS (USDA 2005) for each of the commodities analyzed. The farmer's share of the retail dollar for cereal and bakery products, which includes corn, soybeans, and wheat, is only 5.7 percent. This implies that 94.3 percent of the costs involved in transforming corn, soybeans, and wheat into products that people consume at the retail level are incurred post-farm. By contrast, almost half of the costs of producing beef occur on the farm.

To arrive at the cost of nutrients at the retail level, the costs of nutrients at the farm level are divided by the farmer's share of the retail dollar for each commodity. As shown in Table 2, when the post-farm processing and transportation costs are considered, overall, plant-based nutrients remain less expensive than meat products, but the cost differences are not as stark. At the retail level, energy obtained from any of the crops is less expensive than the least expensive meat item, broilers. In terms of the cost of protein, all crops are less expensive than pork, beef, or milk; however, poultry is a competitive provider of protein, as it is less expensive than corn and wheat and is similar to soybeans. What Table 2 shows is that the cost disadvantage of animal-based products is not nearly as pronounced at the retail level as at the farm level.[2]

Our findings are generally consistent with the nutritional literature investigating the relationship between energy density and cost (e.g., see Drewnowski and Specter 2004, and Drewnowski and Darmon 2005). Of course, this does not mean that vegetarians (or meat-eaters) spend less on food if they supplement corn, soybean, wheat, and peanut items with relatively expensive fruits like blueberries, strawberries, and lettuce. Whereas cheap energy is obtained from some plant-based foods such as bread and pasta, lettuce and strawberries are very expensive energy sources. Nevertheless, other studies have shown that, consistent with our results, vegetarian diets reduce food costs. For example, using consumption data from a sample of French consumers, Drewnowski, Darmon, and Briend (2004) showed that increasing the number of meat products in a person's diet was associated with significantly higher diet costs.

One interesting fact about these nutritional studies is that the authors considered cheap calories as a "bad," arguing that cheap calories lead to weight gain and obesity. Thus, depending upon whether one is more concerned about people becoming overweight or about the economic efficiency of nutrient production, the fact that animal-based foods are relatively more expensive than plant-based foods can be considered a positive or negative. Most vegetarians appear to fall into the latter camp as it supports their argument that vegetarianism results in a more efficient means of producing the world's food supply. Many nutritionists, by contrast, suggest taxing cheap sources of calories under the assumption that the price of such calories is too low from a social perspective.

Of course, as just mentioned, not all vegetarian foods are more efficient than meat in terms of cost of energy and protein produced. Of particular consideration are fruits and vegetables. The production of such foods requires high-quality, productive land. One benefit of livestock production is that cattle, hogs, and chickens can be produced on relatively unproductive land. There are certain types of land that can support only livestock production, with cattle having the ability to produce meat and milk from materials like grasses and forages that would be otherwise inedible to humans. Indeed, Peters, Wilkins, and Fick (2007) recently found that strictly vegetarian or vegan diets required more land to produce food than a calorie-neutral diet that involved the consumption of some meat. The authors concluded that including some meat in the diet resulted in increased

[2] Should large portions of the population convert to vegetarianism, it is unclear how these marketing margins would change. On the one hand, as people rely more heavily on plants for food, the products may undergo more processing to compensate for the loss in variety from forgoing meat. On the other hand, with more food processors focusing on plant products, greater research and economies of scale may cause marketing margins to fall.

Table 2. Cost of Producing Nutrients at the Farm and Retail Levels

Commodity	Cost per Nutrient Produced at the Farm Level			Cost per Nutrient Produced at the Retail Level	
	Cost of Energy ($/kcal)	Cost of Protein ($/gram)	Farmer's Share of Retail Dollar[a]	Cost of Energy ($/kcal)	Cost of Protein ($/gram)
CROPS					
Corn	$0.001	$0.020	5.7%	$0.009	$0.359
Soybeans	$0.001	$0.031	5.7%	$0.017	$0.203
Wheat	$0.001	$0.031	5.7%	$0.021	$0.543
Peanuts	$0.002	$0.035	17.1%	$0.009	$0.206
LIVESTOCK, POULTRY, AND MILK					
Hogs (farrow to finish)	$0.008	$0.218	31.1%	$0.026	$0.701
Cattle (finishing one steer)	$0.019	$0.321	46.9%	$0.041	$0.685
Broilers	$0.010	$0.115	40.3%	$0.025	$0.285
Milk	$0.016	$0.290	31.2%	$0.050	$0.928

[a] The source of farmer's share of retail dollars is USDA (2005). The share for corn, soybeans, and wheat corresponds to the farmer's share of "cereal and bakery products," whereas the peanut farmer's share of the retail dollar is assumed to equal that for "processed fruits and vegetables."

efficiency of land use. They attributed their findings to relative differences in land quality requirements for livestock and vegetable production.

One important observation that arises out of the statistics reported in Tables 1 and 2 is that simple comparisons of the amount of energy/protein consumed versus the amount of energy/protein produced by a plant or animal as in Francione (2004), Singer (2001), or Peters, Wilkins, and Fick (2007) can be misleading. The reason is that many crops, as typically consumed, require significantly higher levels of processing than animal-based products, and as such the full cost of transforming the raw commodities into products that people actually consume needs to be considered. If such processing is also associated with greater pollution (as greater economic activity usually is associated with greater pollution), the environmental benefits of some types of plant-based food consumption are less pronounced when taking into account food processing. Pollution arises from the processing, wholesale, and retail stage of food production as well as the farming stage, yet opponents of modern agriculture tend to focus only on the farm. These authors should consider the entire food marketing channel, and not just one component of food production.

Effect of Reduced Meat Demand on Corn Prices and Production

Arguing that people should become vegetarians based on philosophical and ethical arguments is one thing, but it is an entirely different issue altogether as to how a mass shift towards vegetarianism will affect food prices. As previously indicated, many have argued that producing meat is inefficient. The previous section provided some evidence for this claim, but the simple statistics reported in Tables 1 and 2 do not consider the interrelationship between crop and meat production. How much cheaper or more expensive would crops become if people stopped consuming meat? It is impossible to answer such a question, as this would require extrapolating outside of the world we observe, but it is possible to draw inferences at the margin.

We address this question by turning to the crop sector that is most intimately tied to livestock production: corn. It is difficult to overstate the reliance of modern U.S. livestock production on corn. For example, USDA-ERS data indicate that in the 2004/2005 marketing year, almost 58 percent of corn disappearance was a result of livestock and poultry feed use (Baker, Allen, and Bradley 2007).[3] As such, we focus on the effect of reduced meat demand on corn prices and production. Wheat and soybean are also used as animal feed, though not as extensively as corn. Because soybeans and wheat are substitutes in human food as well, the three crop prices are positively correlated. Other commodities used as livestock feed (e.g., oats, barley) would be expected to exhibit similar, though less pronounced, relationships with meat demand.

As Tables 1 and 2 show, it is less expensive to obtain nutrients from corn by consuming it directly than by using it as animal feed. Thus, if there were a massive shift from meat to vegetarian diets, one might expect a decrease in the demand for corn if the reduction in livestock consumption of corn outweighed the increase in human consumption of corn. If such an effect were to occur, the price of corn would fall, making the cost difference between obtaining nutrients from plants and meat even more pronounced. However, a reduction in the price of corn would reduce the price of meat. To assess these impacts arising from a shift towards vegetarianism, a general equilibrium model of meat and corn markets is employed.

Marsh (2007) recently reported estimates of the supply-demand interrelationships in the livestock-poultry and corn sectors. We make use of the estimates in Marsh (2007) to construct an equilibrium displacement model that specifies the supply and demand equations for corn and livestock as deviations from an initial equilibrium given exogenous shocks to the system [see Alston (1991) or Wohlgenant (1993) for more discussion in equilibrium displacement models]. The estimated supply curves in Marsh (2007) contain lagged dependent variables, allowing for separate analyses of short- and long-run effects. In this paper, we focus solely on the long-run effects, and convert the short-run supply elasticity estimates to long-run estimates by dividing the reported short-run supply elasticities by one minus the coefficient on the lagged dependent variable. The appendix contains Marsh's original equations and a brief discussion on how they were used to arrive at the equations shown below.

The supply and inverse demand equations for corn, respectively, are

$$\text{(1)} \qquad \hat{Q}_{CN} = 0.469\hat{P}_{CN}$$

$$\text{(2)} \qquad \hat{P}_{CN} = -0.371\hat{Q}_{CN} + 0.440\hat{P}_{B} + 0.127\hat{P}_{P} + 0.454\hat{P}_{CK},$$

where the subscripts denote the commodity (CN = corn, B = beef, P = pork, and CK = chicken) and where $\hat{Q}_i$ and $\hat{P}_i$ represent percent change (i.e., $\hat{X} = \mathrm{d}X/X$) in the quantity and price of the ith commodity.

Supply and inverse demand equations for slaughter cattle (beef) are

$$\text{(3)} \qquad \hat{Q}_{B} = 0.817\hat{P}_{B} - 0.278\hat{P}_{CN}$$

$$\text{(4)} \qquad \hat{P}_{B} = -0.565\hat{Q}_{B} + S_{B},$$

where S_B is an exogenous demand shifter we introduced that represents the percent change in the initial equilibrium price for slaughter cattle (beef). More precisely, S_B represents the percent change in willingness-to-pay for slaughter cattle. Greater interest in vegetarianism would reduce the demand for retail beef, which would be translated into a reduced demand for slaughter cattle by the beef processor. A reduction in demand for beef would be represented by a negative value for S_B.

Supply and inverse demand equations for slaughter hogs (pork) are

$$\text{(5)} \qquad \hat{Q}_{P} = 1.555\hat{P}_{P} - 0.710\hat{P}_{CN}$$

$$\text{(6)} \qquad \hat{P}_{P} = -0.641\hat{Q}_{P} + S_{P}.$$

The supply and inverse demand equations for processed broilers (chicken) are

$$\text{(7)} \qquad \hat{Q}_{CK} = 0.695\hat{P}_{CK} - 0.344\hat{P}_{CN}$$

$$\text{(8)} \qquad \hat{P}_{CK} = -0.133\hat{Q}_{CK} + S_{CK},$$

[3] The percentage of corn disappearance that is attributable to livestock feed fell to about 50 percent in 2006/2007, primarily as a result of increased ethanol production.

where S_P and S_{CK} are exogenous demand shifters in the pork and broiler equations, respectively.

To analyze how small changes in the demand for cattle, chickens, and pork influence corn prices, equations (1) through (8) are used. Although some variables such as the boxed beef and wholesale pork price included in Marsh's (2007) original equations (see the appendix) could be considered endogenous in a larger general equilibrium model, one can consider the demand shocks used here as proxies for changes in wholesale meat prices, given that the purpose of including these wholesale prices in Marsh (2007) is to proxy for consumer meat demand.

Equations (1) through (8) represent a system of equations characterized by eight endogenous variables (the price and quantity of each of the four commodities) and three exogenous variables (the demand shifters). Collecting these equations into matrix form, the system can be represented as (9), where X is the vector of endogenous variables, and A and B are matrices containing constants. To illustrate, the first row of the A matrix contains the parameters associated with equation (1), the corn supply equation, and the last row of A contains the parameters associated with the inverse demand for broilers:

(9) $AX = B$, or

$$\begin{bmatrix} 0.469 & 0 & 0 & 0 & -1 & 0 & 0 & 0 \\ -1 & 0.440 & 0.127 & 0.454 & -0.371 & 0 & 0 & 0 \\ -0.278 & 0.817 & 0 & 0 & 0 & -1 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & -0.565 & 0 & 0 \\ -0.710 & 0 & 1.555 & 0 & 0 & 0 & -1 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & -0.641 & 0 \\ -0.344 & 0 & 0 & 0.695 & 0 & 0 & 0 & -1 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 & -0.133 \end{bmatrix} \begin{bmatrix} \hat{P}_{CN} \\ \hat{P}_B \\ \hat{P}_P \\ \hat{P}_{CK} \\ \hat{Q}_{CN} \\ \hat{Q}_B \\ \hat{Q}_P \\ \hat{Q}_{CK} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ -S_B \\ 0 \\ -S_P \\ 0 \\ -S_{CK} \end{bmatrix}$$

Solving for X as $X = A^{-1}B$ identifies the changes in the equilibrium quantities and prices as a function of the three demand shocks. By inserting particular values of S_B, S_P, and S_{CK}, a reduced-form equation showing the response of corn prices and quantity to meat demand shocks can be calculated. For example, by assuming $S_B = 1$, the first element of X equals -0.28, which implies that a one percent decrease in willingness-to-pay (WTP) for slaughter-cattle decreases corn prices by 0.28 percent. Because equation (9) is linear, a 2 percent decrease in WTP results in a 0.28*2 = 0.56 percent decrease in corn prices. Solving equation (9) for corn prices and quantities yields the following:

(10) $P_{CN} = 0.280S_B + 0.059S_P + 0.385S_{CK}$

(11) $Q_{CN} = 0.131S_B + 0.028S_P + 0.181S_{CK}$.

The result in equation (10) indicates that for every one percent decrease in willingness-to-pay for slaughter cattle (i.e., S_B = -1), corn prices will fall by 0.28 percent and corn quantity will fall by 0.13 percent. Similarly, for every one percent decrease in willingness-to-pay for slaughter hogs (i.e., S_P = -1), corn prices will fall by 0.06 percent and corn quantity will fall by 0.03 percent. Changes in demand for broilers have the largest influence on corn prices: for every one percent decrease in willingness-to-pay for processed broilers (i.e., S_{CK} = -1), corn prices will fall by 0.39 percent and corn quantity will fall by 0.18 percent.

These elasticities are calculated using recent empirical data, and thus reflect the supply and demand relationships for the range of prices and quantities observed in recent history. One could choose values of S_B, S_P, and S_{CK} to reflect zero meat consumption, but this would be outside the range of the data used to obtain the estimates, making the corresponding results suspect. [4] However, it is possible to evaluate the impact of a small change in meat consumption on corn prices

[4] Suspect, but not uninteresting. Researchers regularly characterize the amount of oil reserves by counting the number of years left until all oil runs out, assuming oil prices are unchanged as oil becomes increasingly scarce. In a similar spirit, asking how a 100 percent decrease in meat would change corn prices is equally useful, recognizing the assumptions being made. We can simulate the effect of a complete shift towards vegetarianism by finding the magnitude of the demand shocks that would cause a 100 percent reduction in the equilibrium quantity of livestock produced and consumed. Solving for the values of S_B, S_P, and S_{CK} that reduce the quantities of meat produced and consumed to zero (i.e., the values that set $Q_B = Q_P = Q_{CK}$ = -100) yields the values S_B = -236, S_P = -207, and S_{CK} = -242. That is, if willingness-to-pay for slaughter cattle, hogs, and broilers were to fall by 236 percent, 207 percent, and 242 percent, respectively, the predicted equilibrium quantities of beef, pork, and chicken produced and consumed would each fall by 100 percent, to zero. Plugging these demand shifts back into equations (10) and (11) yields the percent change in corn price and quantity that would result from the negative meat demand shocks of such magnitude to eliminate production and consumption of meat. If all consumers were to become vegetarians, the model predicts that corn prices would fall 172 percent and corn production would fall 81 percent. Of course this magnitude of price change cannot be literally true (because it would predict negative prices); however, the results are consistent with the idea that if a mass shift towards vegetarianism were to occur, corn would be *much* cheaper. The reason for the extreme price reduction is that equilibrium displacement models rely on observed data to derive predictions along with the assumption of constant elasticities (i.e., linearity).

as an investigative peek into the consequences of large-scale vegetarianism for corn prices. This is accomplished by assuming that the demand for all three types of livestock falls by one percent. When S_B = -0.02373, S_P = -0.02068, and S_{CK} = -0.02422, the equilibrium quantity of beef, pork, and chicken decreases by one percent. Correspondingly, when the consumption of each farm product falls by one percent due to these shocks, corn prices fall by 1.72 percent and corn quantity falls by 0.81 percent. The results are, of course, sensitive to any measurement errors in the Marsh (2007) study, and standard errors could be calculated using the methods outlined in Davis and Espinoza (1998). This section, however, seeks to provide a best estimate, and thus leaves sensitivity analysis to future research.

This result highlights the interdependency of livestock and corn production. When the consumption of livestock falls by one percent, corn prices fall by almost two percent. One would then conclude that large-scale movements towards vegetarianism would cause large decreases in corn prices, making the cost advantages of vegetarianism even more pronounced. Should the decrease in meat consumption become significantly large, there would be a point where corn prices reached the minimum average variable cost for the most efficient producers, at which point corn prices would become insensitive to changes in meat production, and be at their lowest possible value.

Of course, a shift towards vegetarianism by one portion of the population would reduce corn prices and hence meat prices for the remaining meat-eaters, as lower corn prices reduced the cost of feeding animals. Assuming S_B = -0.02373, S_P = -0.02068, and S_{CK} = -0.02422, corn prices fall 1.72 percent, beef prices fall 1.81 percent, pork prices fall 1.43 percent, and poultry prices fall 2.29 percent. Large-scale shifts towards vegetarianism not only make vegetarian diets cheaper due to lower corn prices, but make non-vegetarian diets cheaper as well. Given these percent changes in prices, movements towards vegetarianism may actually make meat consumption increasingly affordable relative to vegetarianism.

A major motivator for many vegetarians is to reduce pressures on cropland, thereby reducing fertilizer use, pesticide use, and runoff. The model results suggest that movements towards vegetarianism do reduce acres planted to corn. When consumption of all meat products falls one percent, the quantity of corn produced falls by 0.81 percent. Assuming that this lower corn production is met by retiring crop acres, or putting those acres to an alternative, less polluting use, vegetarianism is environmentally friendly. Vegetarians often claim that the reduced corn acres needed for American consumers can be freed to fight famine in developing countries (Spencer 2000, Stuart 2006). However, farmers are unlikely to plant additional corn acres to feed the hungry without compensation. If the negative value for the meat shocks (S_B, S_P, $S_{CK} < 0$) are not accompanied by a positive shock for corn demand ($S_{CN} > 0$), say for example by charities purchasing corn and delivering it to areas of famine, vegetarianism will not achieve its goal of reducing hunger. That is, for the market to remain in equilibrium, the demand curve for corn would have to shift out by an amount equal to the charitable corn donations given to developing countries.

The Value of Meat to Consumers

Many advocates of vegetarianism have argued that most consumers can, without much trouble, eventually switch their diets away from meat consumption. It is true that eating meat is not necessary to live a healthy life (Sabate 2003). However, simply because meat consumption is not necessary does not mean that consumers do not strongly desire it. How strongly do consumers desire meat? According to a leading advocate of vegetarianism, Peter Singer (2001, p. 88), "those who switch to a vegetarian diet will, over time, enjoy their food at least as much as they did before. …" These sentiments are echoed by Reagan (2004, p. 335), who argues that "there are many other tasty foods besides those that include meat …we are not being asked to choose between eating…meat *or* harming ourselves by depriving ourselves of the opportunities for the pleasures of the palate."

In this section, we seek to determine whether there is any empirical evidence for such claims by evaluating the value that individuals place on prohibiting a forced reduction in their meat consumption. This analysis does not assume that individuals decrease meat consumption due to a change in tastes or preferences, such as a voluntary adoption of vegetarianism. Instead, it assumes that tastes remain the same, and that a policy, perhaps driven by significant political power of animal rights groups, forces consumers to reduce their meat consumption through higher meat prices.

Conceptually, the value of meat consumption to an individual is simply the person's maximum willingness-to-pay for each unit consumed less the price paid times the number of units consumed. Thus, the value of meat consumption is simply the area below the meat demand curve and above price. Measuring this value requires an estimate of consumer demand for meat. Although numerous such studies exist in the literature, it is important that the estimated demands are "integratable," meaning that the underlying indirect utility or expenditure function can be recovered from the demand estimates. This is essential because the utility or expenditure function needs to be known to properly calculate the welfare change that would result from eliminating meat from one's diet. In addition to this requirement, we sought published studies that reported sufficient price and consumption information so that changes in the expenditure function could be evaluated. These requirements led us to utilize the food demand estimates reported by Raper, Wanzala, and Nayga (2002).

The food demand estimates reported in Raper, Wanzala, and Nayga (2002) stem from a linear expenditure system. In particular, the authors reported results of a system of demand equations for nine food categories (meat, non-alcoholic beverages, cereals and bakery products, dairy, fruits and vegetables, sweets and sugars, fats and oils, food away from home, and other food at home) applied to a data set on a sample of U.S. households' weekly food expenditures. Nine expenditure equations were estimated for each of the $j = 1$ to 9 goods. The estimated expenditure functions took the form

$$(12) \qquad E_j = p_j \beta_j + \alpha_j (Y - \sum_{k=1}^{9} p_k \beta_k),$$

where E_j is the household's weekly expenditure for the jth good, p_j is the price of the jth food, and Y is household's total weekly expenditure on all nine foods. Pollak and Wales (1969) show that this estimated function implies the following demand function:

$$(13) \qquad x_j = \beta_j + \frac{\alpha_j}{p_j} (Y - \sum_{k=1}^{9} p_k \beta_k),$$

which results from maximizing the following utility function:

$$(14) \qquad U = \sum_{k=1}^{9} \alpha_k \ln(x_k - \beta_k) .$$

Plugging equation (13) into equation (14) yields the indirect utility function, $V(p, Y)$, which depends on food prices and total food expenditure. Inverting this indirect utility function gives the expenditure function $E(p, V)$, which indicates the minimum level of expenditures required to achieve a particular level of utility.

How can this linear expenditure system be utilized to estimate the value of meat consumption? Ideally one would estimate individuals' maximum willingness-to-pay to maintain their current level of meat consumption, as opposed to reducing their meat consumption to zero. Obtaining such estimates requires observations of consumer purchasing behavior when meat consumption is zero or close to zero, and behavior under contemporary levels of consumption. However, no data exists where meat consumption is remotely close to zero. Thus, instead of estimating the value of prohibiting a 100 percent reduction in meat consumption (which would imply vegetarianism for all), we consider a small movement towards vegetarianism. Specifically, this section estimates the monetary value that individuals place on prohibiting a policy that would reduce their meat consumption by one percent.

We generally follow the approach introduced by Hausman (1996) and utilized by Hausman and Leonard (2002) and by Dhar and Foltz (2005). In these applications, the focus was on estimating the value of *new* goods, but the approach is also applicable to identifying people's values for any existing good. The approach is as follows. First, let $j = 1$ represent meat at home and let the current price of meat at home be given by p_1. This implies that the expenditure function at current price levels is $E(p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9,$

V^0), where V^0 indicates utility at current price levels. Second, for the good in question, in this case meat, utilize equation (13) to find the virtual price of the good that would reduce meat consumption by one percent.[5] Let this virtual price of meat be given by p_1^V. Third, determine the compensating variation that would occur from this price change: $CV = E(p_1^V, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, V^0) - E(p_1, p_2, p_3, p_4, p_5, p_6, p_7, p_8, p_9, V^0)$. As the price of meat rises from p_1 to p_1^V, the budget constraint moves inward and changes slope, moving the consumer to a lower indifference curve. Additional income is needed to shift the new budget constraint with its altered slope up to the old indifference curve. The amount of this additional income is the compensating variation *CV*. The calculated compensating variation is the change in welfare that would occur if meat consumption were reduced one percent and the prices of all other foods were held constant at the levels prior to the meat reduction.

Using the data and estimates reported in Raper, Wanzala, and Nayga (2002), we find that meat prices would have to increase 1.012 times their current level for meat consumption to be reduced by one percent.[6] Due to the nature of the data, it is assumed that this meat reduction comes exclusively from food consumed at home. Whereas the average weekly household expenditures on food at mean prices and consumption levels was about \$82.18/week, results reveal that were meat consumption at home forced to fall one percent (i.e., meat prices for food at home increased 1.012 times above current levels), food expenditures would have to increase to \$82.34/week to hold utility constant. This means that the value of eating meat, at home, at current levels relative to a one percent reduction is \$0.16/week (82.34 – 82.18 = 0.16). To put this value in perspective, it is instructive to compare the *relative* value of each food category analyzed by Raper, Wanzala, and Nayga (2002). To conduct these relative comparisons, we carried out the above steps for each food type to determine the change in expenditures that must occur to keep utility constant if the particular food price were to rise to such a level that consumption of that food would fall by one percent. The estimates of the value of each food category are reported in Table 3. Even if we focus on the relative value, we find meat to be the most important food category behind “food away from home.” Of course, food away from home includes meat and non-meat items. Assuming that people eat meat in roughly the same proportion to their overall diets away from home as they do at home, the results imply that meat is the most valuable food group to consumers.[7]

These results suggest that giving up meat is no easy task. Singer (2001, p. 88) argues, in regard to the difficulties associated with not eating meat, that “…these are minor human interests that we should not allow to outweigh the more major interests of nonhuman animals.” The calculations provided here suggest quite the contrary: eating meat is no minor issue for most Americans. Meat is the most valued food source. It is perhaps not too surprising, then, that vegetarians are estimated to represent less than 4 percent of the U.S. population (Ginsberg and Ostrowski 2007); humans derive great pleasure from consuming beef, pork,

[5] There is another, more technical reason for investigating a one percent reduction in meat consumption instead of a 100 percent reduction. In the linear expenditure system, the quantity demanded for good *j* cannot be set exactly to zero if β_j is positive because the utility in equation (14) would be undefined. The coefficient β_j is usually described as the “subsistence” or “pre-committed” quantity level.

[6] Raper, Wanzala, and Nayga (2002) let the β_j parameters vary by demographic characteristics. The results reported in this paper correspond to the level of β_j calculated at the means of each of the demographic characteristics. Although the authors report this value in their Table 4, we obtained slightly different figures when doing the calculation ourselves; thus, we utilize the mean β_j obtained from our own calculations. Raper, Wanzala, and Nayga (2002) also segregated their analysis by poverty and non-poverty households, but we report only the results corresponding to the non-poverty households. Similar results are obtained from both groups.

[7] Some readers may be interested to know whether we extrapolated outside the data to estimate the value of prohibiting a 100 percent reduction in meat. Given the data used by Raper, Wanzala, and Nayga (2002), the closest the data allow to answering this question is to evaluate a 100 percent reduction in meat consumed at home, not counting what is referred to as “subsistence” quantities of meat. Meat prices would have to rise 310 times their current levels to cause a 100 percent reduction in at-home meat consumption, not including subsistence meat quantities. To compensate for this higher meat price, food expenditures would have to rise to \$282.66 per week to hold utility constant. This means that the value of eating meat, at home, to the average household is \$200.48/week (282.66 – 82.18 = 200.48). Stated differently, a person would have to be compensated an extra \$200.48 each week to make them indifferent to whether they eat meat at home, without changing their restaurant consumption habits, assuming the price of other foods is unchanged. This calculation implies an annual value derived from eating meat of almost \$10,500 per household in 1993 dollars. Given that there are roughly 125 million households in the United States, the value of meat consumption to U.S. consumers is about \$1.3 trillion in 1993 dollars or \$1.8 trillion in 2006 dollars. Of course, this result requires one to extrapolate far outside the range of data, but it is a useful way of illustrating the importance of meat in Americans’ diet.

Table 3. Consumer Welfare Loss from a One Percent Reduction in Consumption of Competing Food Categories (in 1993 dollars)

Food Category	Value of Food Category to Consumers ($/week)
Food away from home	$0.606
Meat	$0.162
Other food at home	$0.139
Fruits and vegetables	$0.083
Cereals and bakery products	$0.079
Non-alcoholic beverages	$0.036
Dairy	$0.035
Sweets and sugars	$0.011
Fats and oils	$0.004

and poultry. One may question whether the tastes of consumers would change after a prolonged experience with vegetarianism, or whether children raised in a vegetarian household would develop preferences similar to those reported in Table 3. One cannot question, however, the great extent to which the American consumer values meat.

Conclusions

This paper reported three separate analyses aimed at providing some insight into the economics of vegetarianism. Despite the fact that many vegetarianism advocates routinely make claims about the economic effects of vegetarian diets, there has been surprisingly little systematic study of the economics of vegetarianism. The purpose of this study was to partially fill this void in the literature.

Our initial analysis indicated that it is much less costly to produce nutrients (i.e., calories and protein) from some plant-based sources compared to animal-based sources. This cost advantage, however, is partially offset by the significantly higher marketing bill for crops as compared to livestock. Many crops undergo significant transformation prior to being consumed at the retail level, and it would be a mistake to ignore such costs when comparing the efficiency of nutrient production across animal and plant sources.

In addition to this budget-based approach, we also considered a model of the interrelated corn, livestock, and poultry markets. This analysis suggested that demand shifts away from meat products would result in significantly lower corn prices and corn production. Meat prices fall as well, sometimes by a larger percentage than corn prices. This represents a positive outcome for consumers, as commodity plant-based food would be cheaper and less land would be in crop production (resulting in fewer environmental externalities). However, a reduction in prices and production of crops and livestock implies reduced revenues to the farm sector. Meat production is a value-added enterprise; it takes plants like corn, soybeans, and grass, and converts them into a more valuable item like ground beef and pork chops. Adding this value necessarily requires economic activity, and forgoing this activity would cause economic hardships to those working in the livestock and meat processing sector who would then have to find alternative employment. Also impacted economically will be crop producers, as large-scale adoption of vegetarianism will result in a decrease in the value for their product, especially corn and soybeans. These economic impacts can be significant in the short run, and devastating for some families. Some studies have shown that consumers generally care more about the financial well-being of farmers than farm animal welfare (Norwood, Lusk, and Prickett 2007), so policies promoting vegetarianism may confront additional political obstacles when the public begins to associate vegetarianism with financial hardships in the farm sector. The flip side of this argument is that some types of farms could benefit from an increase in vegetarianism, as consumer demand for certain plant-based foods shifts outward.

Finally, in response to claims made by advocates of vegetarianism, we determined the importance of meat in a consumer's diet. Results revealed that meat is the most valuable food category to consumers. This finding underscores the difficulty activist groups have in prompting a mass shift towards vegetarianism and suggests that the claims that consumers can easily give up meat-based diets are overstated. It could be that the demand and utility parameters used to calculate the value of meat consumption would change once people became accustomed to the vegetarian lifestyle. Children raised in a culture free of meat or animal product consumption may acquire different tastes as well. These are long-term considerations, but persuading individuals to give up meat requires short-term adjustments. The fact that meat is the most valued food source indicates that it would require considerable persuasion for the average American to forgo meat.

There are many issues related to the economics of vegetarianism that this paper does not address. For example, do vegetarian diets lead to better health, and what is the economic value of this improved health? Moreover, the cost of vegetarian diets is perhaps better addressed by documenting exactly what vegetarians eat. Another issue worthy of consideration is the relative magnitude of the environmental externalities imposed by animal- versus plant-based agricultural production. It would also be useful to quantify the costs of increased vegetarianism on the agricultural production sector. Finally, it is important to note that vegetarianism is only one small part of the agenda of many animal rights organizations. It is more likely that such groups will be successful in pushing for changes in the way farm animals are currently raised than in converting large portions of the population to vegetarianism. The question then becomes one of the costs and benefits of improved animal welfare standards.

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Appendix

What follows are the original supply and demand equations reported in Marsh (2007). The long-run versions of these equations were used in the text, and our analysis focused only on the variables pertinent to this study. The supply and inverse demand equations for corn are

$$\text{(A1)} \quad \hat{Q}_{CN} = 4.126 + 0.469\hat{P}_{CN(-1)} + 0.212\hat{P}_{LN} - 0.484\hat{P}_{FT} - 0.412\hat{P}_{SY} + 0.151D_P + 0.011T$$

$$\text{(A2)} \quad \hat{P}_{CN} = -3.387 - 0.371\hat{Q}_{CN} + 0.191\hat{P}_E + 0.440\hat{P}_{B(-1)} + 0.127\hat{P}_{P(-1)} + 0.454\hat{P}_{CK},$$

where the variables P_{FT}, P_{SY}, D_P, and T refer to the price of nitrogen, soybeans, a dummy variable for production flexibility under the FAIR Act, and a time trend variable, respectively. A (-1) in the subscript denotes lagged variables. Supply and inverse demand equations for slaughter cattle (beef) are

$$\text{(A3)} \quad \hat{Q}_B = 1.518 + 0.188\hat{P}_{B(-1)} - 0.061\hat{P}_{CW(-1)} - 0.064\hat{P}_{CN(-1)} - 0.260\hat{P}_F - 0.004T + 0.770\hat{Q}_{B(-1)}$$

$$\text{(A4)} \quad \hat{P}_B = 1.304 - 0.565\hat{Q}_B + 0.754\hat{P}_{BX} + 0.113\hat{P}_{BV} + 0.194\hat{P}_L - 0.001T,$$

where the variables P_{CW}, P_F, P_{BX}, P_{BV}, and P_L refer to the price of cull cows, feeder cattle, boxed beef, cattle by-products, and food marketing labor costs, respectively. Supply and inverse demand equations for slaughter hogs (pork) are

$$\text{(A5)}\quad \hat{Q}_P = -0.457 + 0.241\hat{P}_{P(-1)} - 0.110\hat{P}_{CN(-1)} + 0.008T + 0.845\hat{Q}_{P(-1)}$$

$$\text{(A6)}\quad \hat{P}_P = 4.000 - 0.641\hat{Q}_P + 0.412\hat{P}_{PX} + 0.225\hat{P}_{PV} - 0.027\hat{P}_L - 0.008T,$$

where P_{PX} and P_{PV} are the prices of wholesale pork and pork by-products, respectively. The supply and inverse demand for processed broilers (chicken) are

$$\text{(A7)}\quad \hat{Q}_{CK} = 0.167 + 0.091\hat{P}_{CK(-1)} - 0.045\hat{P}_{CN} - 0.055\hat{P}_{BL} + 0.006T + 0.869\hat{Q}_{CK(-1)}$$

$$\text{(A8)}\quad \hat{P}_{CK} = -0.723 - 0.133\hat{Q}_{CK} + 1.045\hat{P}_{BR} + 0.045\hat{P}_{BX} - 0.003\hat{P}_{PX} + 0.043\hat{P}_L,$$

where P_{BL} is the retail price of broilers.

To convert these equations to their long-run form requires some simple algebra. For example, suppose that a supply equation is written as $Q = a_0 + a_1P + a_2Q_{(-1)}$, where $Q_{(-1)}$ is the value of Q in the previous period. In the long run, $Q = Q_{(-1)}$, so the equation can be rewritten as $Q = a_0 + a_1P + a_2Q$, or $Q - a_2Q = a_0 + a_1P$, or $Q(1-a_2) = a_0 + a_1P$, or $Q = (a_0 + a_1P)/(1 - a_2)$. The equations in the text ignore every variable except the price and quantity changes of cattle, chicken, pork, corn, and the meat demand shocks. The other variables are considered exogenous for our analysis, or alternatively can be interpreted as being subsumed in our meat demand shock variables.