The Allocation of Food to Food Banks

Canice Prendergast*
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Abstract

Food banks throughout the U.S. provide nutrition to the needy. Much of the food that is distributed through food banks often originates with donors - large manufacturers or distributors - far from those needy clients. How that food is distributed by Feeding America, a large not-for-profit, is the subject of this essay. In 2005, Feeding America (at the time the organization was called America’s Second Harvest) transitioned from the centralized allocation process, where they would make decisions based on their perception of food bank need, to one where local affiliates would bid for food items through an online auction mechanism. To do so, Feeding America constructed a specialized constructed currency called “shares” that are used to bid on loads of donated food. The process by which this change came about, its necessary idiosyncrasies, and its outcomes are described.

*University of Chicago Booth School of Business. Email: canice.prendergast@chicagobooth.edu. I am grateful to Carole Theus, Harry Davis, Mike Halligan, Melanie Nowacki and Bill Thomas for much help on this. Thanks also to Eric Budish for helpful comments and to seminar participants at the AMMA, NBER and Rice University. Most of all, however, none of this could have been written without the other members of the America’s Second Harvest Allocation Task Force: John Alford, John Arnold, Al Brislain, Bill Clark, Phil Fraser, Maria Hough, Mike Halligan, Brenda Kirk, Rob Johnson, Susannah Morgan, Steve Sellent, Roger Simon, Harry Davis, Don Eisenstein, and Robert Hamada.
1 Introduction

Food banks throughout the U.S. provide nutrition to the poor and needy. The distribution of food to those in need typically occurs at a local and fragmented level, where food pantries and soup kitchens operate in churches, community centers, schools, and so on. Much of the food is donated by food producers or distributors. Sometimes it originates nearby, yet it often comes from donors far from its end users. As a concrete example, a Tyson Foods plant in Kansas has an extra truckload of frozen chicken. How does this end up in a small food pantry far from Kansas? The intermediary is typically a regional food bank: for example, the Chicago Food Depository provides food to a wide range of charitable organizations throughout the city. The subject of this essay is how a large not-for-profit organization, Feeding America, allocates food to these regional food banks across the United States. Specifically, in 2005 the author was part of a group that designed and implemented a transition from a centralized system, where Feeding America made assignments based on its perception of their needs, to a market-like system based on food bank choice. In this new mechanism, food banks bid on loads of food using a specialized currency constructed by the organization.

Feeding America (the third largest not-for-profit in the United States after the Red Cross and the United Way) is a national human services agency whose mission is “to feed America’s hungry through a nationwide network of member food banks”. It does so through sourcing donations of food across the country, both from large food manufacturers (such as Kraft) and distributors (such as Walmart), and from smaller entities such as local grocery stores, and allocating that food to roughly 210 regional food banks. These solicitation efforts are of two types. First, sometimes donors specify where their donation should go: usually their preference is for a local foodbank. Second, many donors give directly to Feeding America, who then can allocate that food as it sees fit. The subject of this paper is an innovation in 2005 for allocating this second type of donation. At the time of the change, roughly 220 million pounds of food were allocated in this way.

Conceptually, this is not a difficult problem: Feeding America should ensure that the food ends up with the food bank whose need is greatest, taking account of transportation costs, spoilage, and storage issues. In practice, it is much more problematic. The difficulty is not primarily in estimating a measure of aggregate need in a “service area”: one can construct measures of poverty at this level that reflect reasonably well aggregate food needs. Despite this, there remain considerable obstacles in identifying how much any given food bank needs a particular load that Feeding America has

\footnote{So for example, Tyson in Kansas may have a relationship to the Kansas Food Bank and Feeding America’s role is little more than encouraging these relationships and matching these parties when food is available.}

\footnote{There is also data on usage of food pantries and soup kitchens by income level which can be used to fine tune these measures.}
to offer.

First, food banks receive an average of 20% of their food from this source, and Feeding America knows little about much of the other 80%. Some of this variation is transitory, where for example a food bank may already have received eggs this week from another source, and does not really need those being allocated by Feeding America. A second source of variation on the supply side reflects permanent differences, known as “food richness”. Some food banks have close ties with local manufacturers or distributors of food - these are called food rich - whereas others have little access to other food - these are the food poor. Because of these other sources of food, Feeding America typically knows little about what is sitting on the shelves of food banks. Beyond these supply issues, incorporating demand variation is difficult. For instance, regional diets vary across the United States. How should these be addressed? Finally, Feeding America assigns a wide range of food: pasta, produce, frozen meat, baby food, peanut butter, and so on. Some foods are more valuable than others to food banks, so how does Feeding America trade off quality versus quantity in its allocations?

Feeding America sees itself as trading off two key issues when allocating food: (i) incorporating the idiosyncratic food bank demand factors above, yet (ii) simultaneously making sure that those areas with greatest need receive the most food. There are, in general, two ways to attempt to do this: by centralized assignment of food - where Feeding America tells an individual food bank what it gets - or by allowing food banks to choose what they want, perhaps with some prices to guide that choice. Before 2005, the agency (like many not-for-profits) eschewed the use of choice and instead used an algorithm to centrally assign food based on its perception of need.

In 2004, a group of 14 - including the author - was charged with evaluating and appropriately changing the allocation mechanism used by Feeding America.\(^3\) Nine members of the committee were directors of regional Food Banks, three were senior staff at Feeding America, and four were academics at the University of Chicago.\(^4\) That group recommended changing to an allocation system based on food bank choice, where individual food banks bid daily on loads of food. To do so they use a specialized currency called shares that was created by the organization.

This essay is a description of that change and its aftermath. The paper begins by describing the process by which the change came about, and the exact choice of mechanisms. These were designed to be a tradeoff between theoretical considerations leading to efficient allocations, and a degree of simplicity that would allow the Choice System to be implemented on the ground. This is a combination of sealed bid first price auctions twice a day, the ability of food banks to bid jointly and access credit as necessary, an appeals procedure for issues not encountered by the formula for share

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\(^3\) At the time, the organization was called America’s Second Harvest, but throughout this essay, we will refer to the organization as Feeding America.

\(^4\) The members of the Task Force and their affiliations at the time are named at the end of the essay.
access, a simple monetary supply rule, and the revenues generated in any given day being recirculated that evening.

There were a number of objectives in implementing this new market based allocation mechanism. The first was to allow food banks to sort based on their food preferences. There are many ways in which the market can allow sorting. One is to smooth transitory supply shocks: if a food bank already has happened to get yoghurt this month, it can orient its bids away from close substitutes to that product. A second source of sorting is on permanent characteristics, namely food richness. If a food bank already has a large quantity of food anyway, should this change how often it bids and what it pursues? An important issue below is how food banks now choose where to locate on the quality-quantity dimension: do they load up on a large quantity of cheap food, or bid more rarely and only get the high quality things?

The second objective of the Choice System was to encourage more supply of food. Much of the market design literature in economics addresses how to better assign agents to a fixed supply of “slots”: children to schools, courses to students, kidneys to patients, and so on (see Roth, 2008, for a survey). By contrast, one of the motivations for this change was to encourage greater supply of food to the poor. This potentially arises in a number of ways. First, by quickly placing food in the hands of the highest value user, food producers or distributors may be more willing to donate. Second, the greater liquidity generated by the bidding mechanism may make Feeding America more willing to accept donations that it would otherwise fear it could not place. Finally, food banks receive food from many other sources than Feeding America. The new system allows them to sell that food through the allocation system and gain additional shares. These were referred to as “Maroon pounds”.

Following a description of the process, a simple model of framework is offered. This framework is not meant to reflect generality, but rather a tractable apparatus to reflect the particular idiosyncrasies of this setting. Foremost among these is the large number of bidders and the ability of food banks to substitute across both food and time to generate an appropriate portfolio of food for its clients. These lead to an assumption of price taking behavior. In this setting, it is shown that by offering each food bank and equal number of shares per client, and recirculating the supply of shares daily in a symmetric way, the competitive equilibrium arises as an equilibrium of the game. Hence, with price taking agents, these two instruments lead to efficiency. Furthermore, the model offers testable predictions for the value of the Choice System based on the variance of prices and quantities, under the assumption that food banks suffer quadratic losses from deviations from their preferred allocations.

We then consider outcomes. Anecdotally, the change has been an enormous success. On the demand side, food banks are engaged, bid actively, and speak highly of the merits of choice. More concrete outcomes are addressed using data both before and after the change to the Choice System. The results come in two forms. Aggregate outcomes are shown before and after the changeover, where the data post 2005 comes from 65,000 auctions between 2005 and 2011. A more in-depth look is taken on
the actions of individual food banks by considering a single year, 2008, where 12,322 auctions are studied.

A number of indications suggest considerable gains from choice. First, the old allocation mechanism treated a pound as a pound. If it turns out that food banks value all pounds of food relatively similarly, then perhaps the old system was not so inefficient. However, the data show that food banks value some loads of food very differently to others: they routinely pay 20 times as many shares for a desired load compared to an undesired one. Much of this dispersion is generated by the product offered: some food is high quality, some is low quality. As an example, in 2008 food banks could receive 50 pounds of produce for a single pound of pasta. Even if all food banks were ex ante identical, this suggests considerable deviations from equal welfare under the old system, as one food bank could get many lots of pasta and another receive many less desired loads simply by chance.

Most striking is the variation in food bank outcomes over an entire year. This reflects the degree of sorting done by food banks on the quality-quantity dimension. Some food banks choose quantity over quality, while others focus their bidding on the most desired foods. Compared to what would have happened under the old allocation system, 15% of food banks get more than three times as many pounds of food as they would have while another 15% receive less than half as many. Furthermore, regression results show that it is the larger food banks and those that have received other food from Feeding America that are most likely to move up the quality chain, leaving the smaller and food poor banks access to larger quantities of cheaper foods. This suggests that a major beneficiary of the change has been for smaller food-poor food banks. However, other indicators would suggest that this is so in addition. First, they actively use the credit market. Among those who qualify for credit, about 25% of all winning bids involve the credit card. They also have benefited from the ability to jointly bid with other food banks. Finally, many of the safeguards that were introduced at the outset for their benefit have fallen into disuse due to lack of need.

The final objective of the new system was to encourage more supply. The supply of food to the system has increased by between 50 and 100 million pounds depending on how it is measured. There are of course many changes that can occur over time - not least that this arose at the time of the financial crisis - but it seems clear that supply has benefit from the choice system. As one example, within a narrow time window around the change - the first seven months - supply of food rose by 50 million pounds, on a base of about 140 million. Some of this increase can be directly related to the Choice System: during this short period, 12 million Maroon pounds were placed on the market. (The average has remained 12 million Maroon pounds per annum up to 2012.) These Maroon pounds have traded for almost twice the average price of a pound of food, so that these responses are even larger when quality adjusted. Allied to the demand side indicators above, this suggests strong evidence for the value of adding consumer choice to an atypical not-for-profit setting. It is hoped that these lessons may be of some value elsewhere.
2 Allocations before 2005

The old system allocated food based on a metric of need called *goal factors*. This is described more precisely below but was roughly a weighted measure of (i) the relative poverty of a food bank’s service area compared to the nation, and (ii) the relative population of the service area. This was then multiplied by the total number of pounds allocated by Feeding America to construct “goal pounds”: the total number of pounds of food that an affiliate *should* receive. Affiliates were ranked on goal pounds relative to pounds received, with the affiliate furthest below its goal pounds ranked highest. Food was then offered to a food bank based on its rank. This mechanism was used since the late 1980s, and allocated 250 million pounds of food in 2004.

At a concrete level, a food bank would receive a call from Feeding America letting them know that they had been assigned a “load”. This sometimes had conditions, such as a required pickup date. Food banks were (and remain) liable for transportation costs. The choice of a food bank was to either say yes or no. If a food bank refused a lot, these counted against their need measure as if it had been accepted. In effect, they received no credit for what were known as “turn down” pounds, so that need of an affiliate was based not on pounds *delivered* but rather pounds *offered*.

The second exception to the pounds offered calculation was that produce did not count against pounds offered. Produce is a difficult issue for the food banking industry, largely as it need to be moved quickly due to spoilage issues. This is particularly so as produce is sometimes only donated to Feeding America when it is close to spoiling anyway. If an affiliate was offered produce, it did not count against their “pounds offered” calculation. Produce was typically offered first to the nearest food bank to the donor. Finally, Feeding America would make some modifications based on geography: for example, food available in Alabama would sometimes not be offered to the Alaska Food Bank due to its transportation costs.

This allocation system was widely seen by food banks as representing Feeding America’s commitment to fairness, allied to a desire to assign based on need. This sense of fairness was reflected in a number of ways. First, there was also an appreciation that the measures used were transparent. Second, Feeding America only reluctantly intervened to use its discretion over allocations: while it may know that a given food bank was unlikely to accept a given donation (for example, tinned fruit in North Carolina being offered to a food bank in California), they typically stuck to the rules of the allocation system to avoid any perception of favoritism. Despite these benefits, the allocation system had considerable drawbacks. Foremost among these is the absence of demand side indicators: Feeding America was deciding what was

5This may seems strange to the reader: why penalize a food bank for refusing to take food that it does not want? This ignores an important issue faced by Feeding America, namely to maintain donor relations. Donors typically want excess food removed from their warehouses for a variety of reasons - to free up storage space, for tax reasons, and so on. As such, there are pressures on Feeding America to remove food quickly, and that pressure is sometimes felt by the affiliates.
best for individual food banks without knowing what the food banks really wanted or needed. The role for individual choice was minimal other than a refusal to accept goods. Due to the kind of unknown demand and supply information described above, incorporating food bank information was potentially of great value.

A second problem is that the assignment system treated all foods equally (subject to some minor modifications). A pound of potato chips was the same as a pound of frozen chicken. Yet some food is preferred to others: some are nutritionally better, whereas others involve higher transportation costs per pound (potato chips are particularly bad on both counts, whereas peanut butter is especially good). Feeding America did not delve into this issue, as it did not know enough about preferences to apply appropriate “weights”. Instead, it would occasionally intervene in an ad hoc way where if a food bank received a particularly good product (hamburgers, say), it would not get meat the next time its turn came around. While this subjectivity was mostly believed to be exercised in the interests of fairness, it was at times a concern for food banks who worried about how they fared through its exercise.

Much of the discussion below addresses changes to the allocation system to reduce distorted allocations. But isn’t there someone most places that needs the food? It is worthwhile deliberating a moment on the nature of these misallocations. The most obvious - but perhaps least important - is the scenario where the poor in one food bank transitorily fare better than those in another. For example, suppose that Feeding America assigns chicken to one food bank twice in a month, while another gets cereal twice. (Chicken is seen as more valuable than cereal.) While this outcome may not be ideal, perhaps the degree of inefficiency is not so great.

A bigger concern is food that spoils and is not consumed. It is a feature of food banking that a considerable amount of food ends up in the trash, as landfill, or as animal feed. Some of this arises because donors often give food that is close to its expiration date. (Anyone who has volunteered in a food bank will know the experience of having the task of separating edible from inedible food.) This is exacerbated by capacity constraints on storage, particularly for foods that require refrigeration. Here not knowing the residual supply of food banks makes centralized allocation difficult. Take dairy products for example: sending eggs or cheese to a food bank that does not have excess refrigeration capacity - because its fridges are full - likely results in those products not being used. This is also a significant issue with produce.

6In some situations where there is centralized assignment, consumer preferences do not make much difference. For example, a patient waiting for a kidney transplant knows little more than does the hospital involved in the allocation process. Yet in other cases, knowing what consumers want can make an enormous difference. The canonical examples of this are school choice and the medical residency matching system, where parental information is important for optimal school choice and residents have both horizontal and vertical preferences over their preferred hospital.

7This is more of a concern for foods that do not have close substitutes, such as baby food.

8One way around this was informal sharing between food banks. At the time the task force was convened, food banks shared 86 million pounds of food between themselves. For example, if a food bank did not need an offered donation, it could give it to another who might. However, the old
Another important component of this inefficiency is where Feeding America turns down donations that it feels will be difficult to place quickly and effectively due to either spoilage concerns or an inability to pick up within the donor’s deadline.

2.1 The Tradeoff Between Need and Allocative Efficiency

All of the above points to problems that arise with a centrally administered system, one that does not incorporate unknown food bank preferences and constraints. Economists are used to extolling the virtues of consumer choice in allocation mechanisms, with appropriately determined prices guiding those choices. Why not then let the food banks choose what they want?

Consumer choice as an allocation mechanism is predicated on one key premise: that “willingness to pay” by consumers is aligned with the objectives of the organization. In order for consumer choice to play a role, it must be that - through some mechanism - a budget is created, by which we mean that if a consumer raises her hand to say she would like good $x$, it reduces the likelihood of receiving good $y$. Without the creation of such a budget, all hands are raised and so consumer choice becomes uninformative.

The issue here becomes whether an appropriate budget can both incorporate unknown food bank preferences and simultaneously meet their overall needs. The most natural - and common - way to create such a budget is to attach prices to goods, and let consumers choose. In that way, preferences are incorporated as consumers compare the value of a good with alternative uses of their money. Consider this possibility in the context of food banking, where Feeding America could sell the food to the food banks, perhaps at subsidized prices. Such pricing occurs further down the supply chain of food banking. For example, soup kitchens and food pantries in Chicago pay to receive some food from the Chicago Food Depository, where different food carries different (subsidized) prices. In this way, local food pantries are required to “put their money where their mouth is” to better reflect the strength of their preferences.

While this kind of pricing helps to identify whether a given food bank wants pasta...
or fish, it is less clear if it satisfies Feeding America’s desire to locate most food with the neediest food banks. For this to happen, the food bank in greatest need must have the biggest budget. There is little confidence that in reality it would: instead, there is a very real danger of the opposite. Food banks would rely on fund raising to pay for this food, and those food banks in the areas of greatest need may have the least access to fund raising, thereby exacerbating the problem. Because of this, Feeding America was reluctant to use the price system in any meaningful way and instead used centralized assignment, despite its warts.

In sum, centralized allocation fails to reflect food banks’ idiosyncratic demands, while pricing with real money fails to offer budgets based on need. Given this, how about consumer choice with fake money? In theory, these two problems are separable: prices can be used to orient choice, and a free hand in choosing budgets could potentially satisfy overall need. As such, it became a promising candidate to resolve both problems.

3 The Choice System

When the Task Force convened to discuss a redesign of the allocation mechanism, it became clear that there was considerable discontent at the misallocation of food, often leading to spoilage. The example that routinely cropped up was when the Idaho Food Bank was offered potatoes, even though they already had a warehouse full of potatoes. Despite this, when the idea of a “market” was introduced as an alternative, it met with considerable resistance in many quarters. Food banks exist to serve the marginalized, often those that the market economy has left behind. The preferences of food bank directors often reflect that concern for marginalization, and a fear that markets tend to benefit the strong or powerful. Consequently, while the Task Force was open to change, the initial response to a consumer driven choice system was muted. As one food bank director told the author, “I am a socialist. That’s why I run a food bank. I don’t believe in markets. I’m not saying I won’t listen, but I am against this”.

The group met for over a year before converging on what is called the Choice System, using a currency called shares to bid on loads of food placed onto the system. Before describing its details, it is important to note that its ultimate introduction lay not in its broadest conceptualization. One indicator of this more generally is that specialized currencies are very rare in reality. Instead, the success of this innovation

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12 The example that has received most attention in the market design literature has been the use of bidding systems for business school classes at top universities, where students are given points to bid on courses. In the absence of a some kind of budget, too many students want to take the most popular classes and some centralized assignment mechanism would be needed to allocate slots. Many top business schools now give bidding points to students that allow them to reveal the strength of their preferences for particular classes. While these mechanisms are not without their problems - especially as students have to bid on schedules, not courses - the central idea is that the creation of
lay in the myriad of tweaks and additional institutional details that were necessary both for buy-in from the relevant constituents and reflected important considerations on the ground. None of the academics involved in this redesign - the author included - understood the many pitfalls that could have derailed the implementation of this system successfully: for that they relied heavily and consistently on the food bank directors and the staff of Feeding America. The new system would not have occurred without a willingness to listen and adapt on both sides, and the patient and expert moderating of one of our members, Harry Davis.

The starting point of the new system was the creation of a currency called shares. These shares could only be used to bid on what Feeding America calls “yellow pounds”. These are the donations that are made directly to Feeding America, and as mentioned above accounted for about 250 million pounds of food. The donations made to a specific food bank that were alluded to in the introduction (and called “blue pounds”) were not included in the new Choice System. Shares could not be traded for real money nor used for anything other than the items on the auction market described below.

At the outset of the Choice System, Feeding America distributed shares to each food bank. Shares were initially allocated to a food bank based on its goal factor, so the neediest received the biggest budgets. Food banks then logged onto a website on which were posted a set of offerings of food: for example, a truckload of pasta from a food distributor in Tennessee. The offerings sometimes would have conditions: most commonly, how quickly the food needed to be picked up. At the time of implementation, there were approximately 30 to 40 offerings a day.

Based on this information, food banks would then use its shares to bid on any lot that they wished and could afford, and the winner of the auction was the food bank who bid most. The price paid was the bid of the highest bidder. That number of shares would then be subtracted from the winning bidder’s balance. Any items that did not sell on a given day would be carried over to the following day for more bidding. Balances did not depreciate.

All shares that were spent on a given day were redistributed at midnight. The rebalancing was done using the same formula as the initial allocation, where the most needy received the greatest fraction of the spent shares. Hence, any food bank which had not purchased on the previous day would almost always have a higher balance the following day, with a greater increase for those in most perceived need.

This describes, in the broadest brush, the central details of the auction mechanism and the allocation of shares. However, fairness considerations dominated much of the
group discussion, and many of the more precise details below reflect those considerations. In most cases, the concerns were not about who got how many shares, but rather other potential inequities could result in a playing field which might favor some food banks over others:

- The first concern was for the “little guys”. Food banks vary in size and organizational sophistication, ranging from small banks with a couple of employees operating on a shoe string, to larger outlets in major cities with many employees. A concern that arose consistently was that the allocation process should not harm these smaller food banks relative to their larger counterparts.

- Probably the greatest difficulty in designing the system concerned the issue of “food richness”. Areas that have a denser network of food producers and distributors likely have more sources of alternative food than those that have few. Leveling the playing field in favor of food poor areas was a consistent source of discussion.

- A broader characterization of the food rich issue is unmeasured need, factors affecting need that are not captured in the goal factor. For example, what happens if there is a natural disaster in an area? Or, more commonly, a plant closing in a town? The old system allowed for some discretion by Feeding America by bumping food banks up on the priority list. Finding some way to incorporate these unmeasured needs was a concern.

The details of the Choice System, to which we now turn, reflect these (and other) concerns.

3.1 Bidding and Prices:

**Bidding:** Bidding occurs twice a day with sealed bids, with the winner paying the number of shares bid by the winning bidder. Bidding closes at noon and 4pm, with the outcomes being revealed immediately by email after bidding closes. All food for each bidding cycle is posted at least two hours beforehand. The technology allows a food bank to search only for items it might have an interest in, by excluding items based on either geographical constraints or certain kinds of food. A simple click also reveals the history of prices for similar items.

**Joint Bidding:** Food banks have the opportunity to bid jointly for items. Multiple banks coordinate by choosing fractional bids.

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15The group went back and forth on what price would be paid by winning bids. A desire to minimize strategic considerations led to some members arguing for a second price auction, but the sense among the participants in the process was that the clarity of “you pay what you bid” was more important. As a result, a first price auction was chosen.
Delegated Bidding: Food banks can delegate bidding to Feeding America. To do this, they call a delegate at Feeding America and explain their needs, who bids on their behalf.

Credit: The food banks with greatest need can access credit. Specifically, they can increase their balances to the estimated cost of a highly desired item, where they pay off those debts with at least half their future allocations until the debt is paid off. There is no interest rate on these debts, and future credit cannot be attained until debts are paid.

Clusters: Some food banks have chosen to join together for allocation purposes. These are known as clusters. These entities will continue to bid as clusters.

Many of these institutional features reflect the concern for the smaller food banks. A worry that was raised early in the deliberations was that larger food banks could dedicate a staff person to the bidding process and if there was continuous bidding, those food banks could wait until the last minute and “snipe”. Smaller food banks, which may have one or two employees, could not do this, and would ultimately lose from a system that placed a return to frequently checking the website. This was partially averted by twice-a-day sealed bid auctions, with all food posted at least two hours beforehand. It is worth pointing out that this is not without costs in this context: sometimes donors offer goods which need immediate pickup and the twice a day sealed bid process can make these donations problematic.

A second concern for smaller food banks is through an important indivisibility, in that a truck is needed for transportation. Larger food banks can typically use a truckload of any offering, whereas their smaller counterparts may only be able to effectively distribute say a quarter of a truckload. The joint bidding provision was implemented to aid smaller food banks to fulfill their needs while overcoming indivisibilities. Here two (or more) food banks would agree to split a truckload offering, where they submit online the fractions of who pays what.

Delegated bidding was also offered as an option to a food bank that simply did not feel that it had the resources to effectively manage the process. Those food banks could call Feeding America to let them know their needs and allow Feeding America to bid on their behalf. Such delegated bidding could also be done temporarily, say when the food bank director is on vacation for some period of time.

Finally, a concern that arose frequently - which we return to below - is that the smaller entities might never receive the most desired products. This was because a truckload of the most desired goods would likely sell for a larger bid than their balance of shares. This issue was circumvented by allowing most food banks access to enough shares to purchase the most desired options. As the larger food banks typically would

\[16\] It is worth noting that some offerings on the market are Less Than Truckloads.
hold a balance larger than this on any given day, this was only offered to the smaller and more needy food banks.

**Hard-To-Move Product and Negative Prices:** Under the old system, there was a degree of arm twisting that arose for product that the food banks did not want. This arose beyond the fact that if a food bank refused a product, it counted against future offering in exactly the same way as if the offering was accepted. This was done to maintain donor relations. The new system allowed for negative prices for goods, called “bonus shares”, where shares would be credited to accounts of those food banks that would agree to take a product. In the first day of offering, bonus shares were not offered on a good, and the lowest bid possible was 0. However, if there were no bids after day 1, food banks could bid negative shares for lots (up to a limit of -2,000 shares per load) and the good is assigned to the food bank that offers the smallest number of negative shares.

This is largely transparent, and the negative shares an attempt to add consumer preferences into these hard-to-move items. The only unusual feature is that negative shares were not offered on day 1. This feature was introduced because there was a concern that if smaller food banks do not check offers every day, they might miss the opportunity to get bonus shares. The two day process gave them more time to see that they could gain shares from bidding on an item.

### 3.2 Unmeasured Hardship

As mentioned above, the old allocation system allowed a degree of discretion, where Feeding America could change rankings based on non-statistical metrics. In order to allow such discretion in the Choice System, a Fairness and Equity Committee was instigated. This committee, whose members would be other food bank directors, would meet quarterly to review applications from individual food banks who make a claim that their allocation of shares should exceed those currently offered under the measures of poverty included in the goal factor.

The committee could increase the goal factor of a food bank by up to 50% for up to three years, thereby entitling them to more shares. This would be used for both temporary relief measures, such as with a natural disaster or a plant closing, but also potentially for more permanent issues such as documented food poorness or high cost of living areas. The Fairness and Equity Committee would fund these extra shares offered to food banks through an annual allocation.

### 3.3 Supply

Market design solutions are often aimed at better matching unknown consumer demands to a fixed supply of “slots”: schools to children, kidneys to patients, classes to
students, and so on. So far, our discussion of the Choice System has largely reflected these concerns. However, a significant issue throughout the deliberations was how to generate more supply of food for the poor, both from traditional food donors (producers and distributors) and also from food banks themselves. This could potentially occur in a variety of ways:

**More and better supply from traditional donors**  Much of Feeding America’s activities come in soliciting donations of food from manufacturers, distributors, grocery stores, and so on. The new system potentially allows further inducements to donate:

- The central objective of the new system is that food be used by those who need it most. One way in which donations could be more effectively solicited is with the message that any food given will be used to the best possible end, as the market will allocate food more efficiently.

- The ability of the Choice System to create liquidity (through many food banks bidding on food) could result in Feeding America accepting donations that were previously denied, due to a fear that they could not be quickly placed with a food bank.

- An auxiliary outcome of the Choice System is to identify those foods which are most valued. Previously there were no good indicators of what foods were most desired by end users: now there are prices. These prices could be used to focus solicitation on those donors who have the highest valued foods by users.

**Maroon pounds**  Above, we described two kinds of offerings: yellow pounds (those donated to Feeding America) and blue pounds (those directly donated to specific food banks). The Choice System added another source of food called *Maroon Pounds*.

Maroon pounds are foods that an individual food bank already has, perhaps from another source, but for which it may not be the highest value user. It could be that a food bank already has something, but wants something else. (One example could be where a food bank wants quantity over quality, and sells high value chicken or fish to get a larger supply of pasta.) An alternative use of maroon pounds is where a food bank has food that will spoil before it can use it. Finally, the ability to resell food may make a food bank accept a donation when they cannot use the food themselves, but someone else can. The Choice System facilitated this by allowing food banks to place these on the market. These are bid on in exactly the same way as other product, but where here the winning bid is transferred to the seller rather than redistributed to all food banks.

These maroon pounds are designed to allow a final source of improved food distribution, which is through the ability to mix loads. Say a food bank has won three bids,
with a truckload each of baby food, pasta, and tinned salmon. A smaller food bank may have no interest in an entire truckload of any of these, but would be interested in a truck that has a third of each. Mixing arises when a food bank takes these loads, reconfigures them, and then places them back on the market as Maroon pounds.

These Maroon pounds are treated differently to other offerings in two ways. First, they are not eligible for bonus shares (the negative prices), as their donor issues have already been resolved. Second, they are taxed. Specifically, a tax of 10% is imposed on the seller of any Maroon shares transacted.\footnote{The tax revenues were given to the Fairness and Equity Committee for disbursement.}

The issue of taxing donations from outside the system was the subject of considerable discussion. The ultimate decision to tax these revenues revolved around a revealed preference indicator of “food richness”. As mentioned above, there was a desire to level the playing field based on food richness. However, the Task Force was largely unwilling to “tax” food richness using objective statistical measures of such richness, such as the presence of large food producers or distributors in a service area. While it was generally acknowledged that these were likely correlated with food richness, staff or food bank directors were quick to point out exceptions: for example a food bank, which though located close to a major food distributor, was actually food poor. These exceptions rendered it impossible to use such measures in computing goal factors. Instead, there was more comfort with dealing with the food rich issue through revealed preferences. Specifically, if a food bank was putting food onto the market for shares, they probably had more than enough for themselves. As a result, maroon pounds became the revealed preference metric for food richness, and this became the reason for taxing them.

As a summary, Figure 1 gives a screenshot of the website facing a food bank on a typical day. This lists the available offerings, their location, the number of pounds, and whether a subsidy for transportation is being offered. Bidders then can place their bid, knowing from the data below their available shares and access to credit. To the left of the screen are tools that offer historical price data, and also gives a food bank the option to offer Maroon pounds to the system. Two such screen will be seen each day, one for the offerings at noon CST and the other for the 4pm auction. As noted above, the outcomes will be sent by email to all bidders immediately at the close of the auction.

### 3.4 Other Rollout Issues

**Technology:** The clarity and simplicity of the technology used played a central role in the Choice System. Before it went live, food banks had played a demonstration version, designed by Don Eisenstein and implemented by Mike Halligan, for over three months and were familiar with its operation.
**Buy-in:** Feeding America is a democratic institution and the food banks voted on whether to pass the new proposal. The work for this was done by the food banking and staff members members of the committee, and it would never have been introduced without their commitment. At the end of their efforts, the new proposal passed resoundingly.

**Other:** The subject of this essay is to understand the transition of the allocation system from one that is administered to one that involves client choice. However, in the interests of completeness, it is worth noting that this group dealt with a number of other concerns. Two stood out. The first was a change in the definition of need, the “goal factor” used in calculating relative allocations. This is described in the Appendix. Second, due to a previous merger, Feeding America inherited some additional food banks which shared a service area with an exiting food bank. Previously these “Food Rescue Organizations” were not offered food through the allocation system, but they were successfully added as part of this process.

### 4 Money Supply Concerns

This system operates using the constructed currency of shares. Feeding America controls the supply of shares, and an important issue is what governs that supply. The main touching point of share supply on efficiency is through price transparency. A concern of a system such as this, with constructed currency, is that participants may find it difficult to know how much to bid for an item. To describe this slightly differently, it is typical for economists to extol the virtues of auctions, as bids reflect valuations. Yet valuations have to be denominated in some numeraire, and in normal markets, it is the usual Lagrange multiplier measuring the marginal utility of income. Here the numeraire is the marginal value of a share. Yet how can a food bank compute the marginal value of a share?

Individual food banks typically know nothing about the aggregate supply of shares in the system: all they can see are their balances and the prices of transacted lots. In order to aid bidders in making bids, it was felt that the historical price of a particular good should provide strong information about a reasonable price now. So, for example, seeing that a truckload of bread sold for 1,000 shares in the past would be a good indicator of the current market for bread, all else equal.

As a result, the desire was to choose share supply to generate zero inflation for a given good if demand and supply conditions are unchanged.\(^{18}\) To that end, the system was designed such that the historical record of previous prices would be a strong reflection of current valuations.

\(^{18}\)This was felt to be particularly pertinent in the context of leveling the playing field for the “little guy”. The reason for this is that smaller food banks may bid on a particular item (bread in Massachusetts, for example) quite infrequently compared to larger food banks, and this may give larger food banks an advantage in bidding as they know better how to compute reasonable bids.
Zero inflation as a theoretical objective is easier said than done in reality. To see this, consider the simplest Quantity Theory of Money

\[ MV = PT \]  

(1)

where \( M \) is the money supply (here shares), \( V \) is the velocity with which it is transacted, \( P \) is the price level, and \( T \) the quantity of transactions. The desire here was to try to ensure that \( \dot{P} = 0 \), *everything else equal*. What should be held equal is empirically a harder question to answer.

Some sources of price variation should clearly be filtered out via changes in the supply of shares. For example, suppose that \( T \) doubles from one year to the next (holding its composition constant). If the number of shares is left unchanged, prices would likely deflate by 50%. Hence, the number of shares would need to be scaled by the supply of goods on the market. Yet \( T \) is value weighted, so it may not be enough simply to scale the supply of shares by the number of pounds in the system. Specifically, the composition of \( T \) can also matter, and the makeup of the food supply changes considerably over time.\(^{19}\) For example, if the supply of shares is held fixed, and say low value potato chips are substituted with high value peanut butter, the prices of all other goods will fall. Ideally, the share of supplies should be changed to reflect changes in average values of transactions.

Finally, there may be variation in \( V \), the velocity with which the shares are traded. Two potentially sources of such variation arise. First, when the system began, participants did not yet know how to play and the concern was that velocity would be low until participants understood the game. Second, food banks are liable for all transportation costs, and changes in gasoline prices have a first order effect on their willingness to engage in the allocation process. For all these reasons, maintaining constant prices is empirically tricky.

Yet at the same time, there is information in prices that is important for determining demand and should not be filtered out. A prime example is the seasonality of the price of produce, which is important for guiding demand. As a result, one does not want to change the money supply in such a way that seasonal fluctuations are extracted. Furthermore, there could be changes in the aggregate supply of a given kind of good from year to year that should be reflected in changed prices.

The resolution to these issues was that Feeding America would track one measure of aggregate \( T \) - pounds supplied to the market - and adjust the money supply accordingly every year. This does not control volatility in the velocity of transactions, nor changes in the quality of food being offered to the Choice System, but would at least allow some adjustments based on total donation of pounds to the system.

\(^{19}\)Charitable organizations often benefit from industry’s mistakes, as usually donations are generated by inventory errors, where a firm or distributor produced or ordered too much. As firms become better at managing inventory, Feeding America is affected. This may vary by food quality.
Daily Reallocation of Shares  All shares that are spent in a given day are reallocated at midnight. The shares are reallocated according to the same goal factor formula, where those in greatest need are topped up at a greater rate than those who are less needy.

There were a number of reasons for this. First, to maintain constancy of the “money” supply: if for example, the alternative was to only reallocate at the end of a given month, aggregate spending in the month could affect extant supply and hence prices in an undesirable way. Second, we wished to avoid the problem of food banks having to budget over any discrete time interval, with the danger of running out of money at the end of the month, or spending too much at the beginning of the month, much like the evidence on Food Stamp use (Shapiro, 2005).

Finally, and most importantly, one of the biggest conceptual hurdles faced in this process was to inculcate in the minds of the food banks that they are the owners of the food being donated, and not Feeding America. In effect, they are not only the buyers of the food, but also the sellers. This is not meant in the literal sense of food banks putting their own Maroon pounds onto the market, but rather the food that comes from Feeding America.

This became particularly pertinent when concerns were raised about the danger that only the large, food rich food banks would receive the most desirable items, as they would bid more than any other food bank. This was seen by many on the task force as inherently unfair: that the large food rich banks would get the “good stuff”, leaving the rest for the others. This concern became mitigated when it was pointed out that the beneficiary of these high priced sales was not Feeding America but rather the rest of the food banks. This is because those shares would be reallocated to everyone else at midnight. The author remembers one of the other food bank directors on the committee joyfully pointing out “so if Los Angeles bids us out of the market by paying a fortune for a truckload of frozen chicken, we really get their shares that night?” That sense of ownership through the reallocation of shares indirectly helped buy-in across the food bank network.

5  A Simple Framework

The purpose of this section is to offer a simple framework that offers some theoretical outcomes and, as importantly, implications that can test for the benefits of a system based on choice. The framework below is based on a number of assumptions. The first is anonymous price taking behavior, where strategic behavior of participants in their bidding is minimal. The case for price taking relies on the nature of the auction.

Note that strategic behavior by bidders cannot be ruled out purely on theoretical grounds. This is a first price auction, and only under special assumptions will this generate the usual efficiency outcome where the most valued bidder always wins and does so at the price of the second highest bidder. Specifically, revenue equivalence can fail when bidders have asymmetric valuations for goods. Such asymmetries are a central part of the welfare gains from the market below, and as such -
First, previous theoretical research has shown how the benefits of non-price taking behavior rapidly become small as the number of bidders rise (Rustichini et al., 1994). Here there are 215 food banks that can bid on food, so “n” is very large. Of course for any given load in a specific location, the number of active bidders will be much lower, but this auction is far from the small numbers case one often sees.

Second, and likely more important, is that there are enormous substitution opportunities available for food banks such that these market power issues become very small. The first source of substitution is where food banks can substitute across foods. For example, a food bank will see tinned peas as a close substitute for tinned beans, or will see rice as a close substitute for pasta or potatoes. The existence of close substitutes on the food end mean that there is not a lot of variation in willingness to pay (per unit of quality) across food banks. As a result, an appropriate lens to view the objective of the food bank is a hedonic, where they bunch foods by quality and seek a desired distribution of quality. Another source of substitution arises as food banks are often largely indifferent about whether they receive a load of usable food this week or next week. The objective of food banks is largely to ensure a sufficient range of foods over say a month. They view their world in what we call “intervals” below, where they seek a range of foods over the length of that interval. Such opportunities for inter-temporal substitution also restrict market power as all food bank who will serve say pasta within two weeks from now will bid on it today. For these reasons, strategic bidding is ignored below.

The second part of this assumption is anonymity, where all food banks perceive themselves to face the same hedonic prices. This is discussed below.

The other important feature of the framework below is food richness. When we examine the data below, one noticeable feature of the Choice System is that there are a number of food banks who bid rarely, but when they do, they bid only on the most desired loads. Those food banks already have enough of the staple foods - indeed for storage reasons they often cannot store additional supplies of these staples. As a result, they tend to hold back their shares for the most desirable products, and bid aggressively to win these offerings. This leaves the staples and low end goods for the food poor regions. Variation in food richness plays an important role below.

5.1 Framework

There are two goods, A and B. Good A is the lower quality good and good B the higher quality good, at least for larger quantities of those goods. Think of goods A and B as aggregates of lower quality and higher quality goods to the Choice System. The game played is repeated, beginning in time period $t = 0$ and continuing ad infinitum to $t = \infty$. A period $t$ of the game is a day, where on any given day some donations are made, and $n$ food banks can bid. ($n$ here is 215.)

theoretically at least - strategic bidding cannot be ruled out.
Demand  Although bidding occurs every period, consumption occurs over a discrete “interval”, which lasts $T$ periods. (Think of this as a month or a quarter.) I refer to each $T$ period length as an interval $I$. For an interval $I$, the food bank has preferences defined over total quantities of the two goods that they consume in the interval. The return to good $A$ is quadratic, while the return to good $B$ is linear. Utility from food bank $k$ having total consumption of the two goods $x_{AIk}$ and $x_{BIk}$ in interval $I$ is

$$U(x_{AIk}, x_{BIk}) = \tau x_{AIk} - \gamma \frac{x_{AIk}^2}{2} + x_{BIk}. \quad (2)$$

This utility function is meant to reflect the fact that there are some foods - the low quality staples - that suffer diminishing returns. Produce is plentiful, and beyond a certain point, it is likely to spoil or not be taken by clients. By contrast, high quality food such as cereal or chicken is always highly valued as it is sufficiently rare. Food bank $k$’s total utility is given by the sum of its utility over all intervals

$$V_k = \sum_{j=0}^{\infty} U(x_{Ajk}, x_{Bjk}) \quad (3)$$

and the objective of the principal is to maximize the sum of all food bank $V_k$’s. Note that this formulation does not include the number of clients as an argument. Consider the formulation above as consumption per client, where when the use of equal shares is made below, this refers in reality to equal shares per client. This simplification is solely to cut down on notation.

For notational simplicity, from now on the subscripts $I$ and $k$ are dropped unless necessary. The assumption of quadratic preferences is to allow a closed form for outcomes that allows testable implications of the market through measures of dispersion in relevant variables.

Supply  Before considering how each food bank accesses food, we assume that good $A$ is more abundant, where the ratio of supply of good $B$ to good $A$ is given by $\mu < 1$. Supply of each good to a food bank comes from two sources: allocations from the system and other endowments. Consumption $x_i$ has two parts: an endowment $D = (D, \mu D)$, where $D$ is the supply of good $A$ and $\mu D$ the supply of good $B$, and consumption generated through quantities attained through the auction $q_A$ and $q_B$.

The relative supply of goods on the auction market is also given by $\mu$, though this symmetry is simply to cut down on notation.

To simplify, we consider variation across food banks as binary, the “food rich” and the “food poor”: half of all food banks are food rich and the other half food poor. Let $\underline{d} = (\delta d, \delta \mu d)$ be the endowment of the food poor of goods $A$ and $B$ respectively, and $\overline{d} = (d, \mu d)$ be the endowment of the food rich, where $\delta > 1$. An important variable below is $\delta - 1$, which measures dispersion in ex ante endowments.\footnote{In reality, some of these differences are permanent and some are transitory: for the time being}
In each period $t$, a supply of goods A and goods B arrives. While the supply in a given period is potentially stochastic, with $q_{AIt}$ and $q_{BIt}$ the supply, we assume that in every $T$ periods, total supply is fixed and deterministic, where $Q$ is the supply of good 1 and $\mu Q$ is the supply of good 2. (This assumption is meant to capture the notion that a food bank may have little idea what will be coming on the market today, but over a month or a quarter they have a good idea of the relative supply of high and low quality food.) Furthermore, these daily supplies could be indivisible, yet it is assumed that $Q$ is sufficiently divisible across the food banks.

**Budgets and the Money Supply** At the beginning of each interval $I$ of the game, food bank $i$ is endowed with a supply of shares of $s_{iI}$. These shares are chosen by the principal, and can depend on the identity of the food bank but must be history independent.\textsuperscript{22} These share can be used to bid on the quantities. At each period $t$, each of the $N$ food banks can place a bid for a unit of food, and makes a bid $b_{AIt}$ for a unit of good A and $b_{BIt}$ for a unit of good B. The winner of the auction is the food bank that makes the highest bid, and a price of $b_{ItI}$ in shares is paid by the winner (a first price auction).

At the end of each period, all shares spent are reimbursed to the food banks, so that if total revenue generated is $R_{tI}$, each food bank’s stock of shares is changed by $R_{itI}$. So for example, more shares could be given to one food bank rather than another. Once again, these are history independent. This process continues until the end of the interval. The food banks carry over their final balances to the next interval with additional transfers $s_{i(I+1)}$. The next interval then begins, with the same steps, except that the principal can choose a different level of shares and a different way of reallocating them if she so desires.

**Timing** The timing of the model is as follows. At the beginning of the game, the principal commits to a rule $(s_{iI}, R_{itI})$ for all $i$, $I$, and $t$. In any interval $I$, all parties know $Q$ and food bank $i$ begins with $s_{iI}$ shares. At each period $t \geq 0$ in that interval, all participants observe $q_{AIt}, q_{BIt}$ and on the basis of this, they bid $b_{AIt}, b_{BIt}$. If bids are tied, the winner is determined randomly. The shares are then reassigned according to $R_{itI}$. This ends period $t$, and period $t + 1$ begins, with the principal making additional transfers $s_{i(I+1)}$. At the end of period $T$, consumption occurs and the next interval $I + 1$ begins. This continues ad infinitum.

\textsuperscript{22}This was a constraint of the process where the food banks signed up for the Choice System: attempts to make share allocations depend on purchase history proved infeasible. While such reallocation could be used for redistribution purposes, it was politically infeasible.
5.2 Competitive Equilibrium

Begin by considering the competitive equilibrium of an interval, ignoring all other intervals. This program maximizes the weighted utility of both parties, subject to each party preferring their own allocation to that of the other party. The allocation mechanism below implements equal weighted utility, so we consider those weights. The utility of type $D$, where $D \in \{d, \overline{d}\}$, in an interval is given by

$$U(q_A, q_B; D) = \tau(D + q_A(D)) - \gamma \left(\frac{(D + q_A(D))^2}{2} + q_B(D) + \mu D\right).$$

(4)

The competitive equilibrium (defined in the Appendix) consists of four outcomes: $q_A(D)$ and $q_B(D)$ for each of the two $d$'s, subject to these being non-negative and being feasible.

The central issue for competitive equilibrium is the difference in endowments between the food rich ($\overline{d}$) and the food poor ($d$). These induce differences in marginal valuations all else equal. If $Q$ is large enough, these differences can be overcome such marginal rates of substitution are equated. For notational simplicity, let $q_A(d) = q_A$ and $q_A(\overline{d}) = \overline{q}_A$. Equating marginal rates of substitution implies that

$$q_A = \frac{Q}{n} + (\delta - 1)d,$$

(5)

and

$$\overline{q}_A = \frac{Q}{n} - (\delta - 1)d.$$

(6)

At these quantities, total consumption of good $A$ for both is $x^*_A(Q) = \frac{Q}{n} + \frac{\delta + 1}{2}$.

For this outcome to be possible, two conditions must hold. First, $Q$ must be high enough to allow equation of marginal utilities. Second, the competitive equilibrium implies that the food poor receive more than their share of good $A$. But this means that the food rich must be “bribed” by getting more of good $B$, which requires that there be enough good $B$. These two conditions are formalized in Lemma 1.

Lemma 1 If $\frac{2Q}{n} \geq (\delta - 1)d$ and $\mu \geq \mu^*$ where $\mu^* = \frac{2\tau(\delta - 1)d - \gamma d^2}{n} \left[\frac{(\delta - 1)^2}{4} - \frac{(\delta + 1)^2}{4}\right]$, then the competitive equilibrium is characterized by (5) and (6).

So far, we have defined the amount of good $A$ that is assigned to each party in this equilibrium. What about good $B$? Here there are a range of allocations that are competitive, as all that is necessary is that either party does not want to deviate to the other’s allocation, and there are potentially rents to both parties.

We focus on one particular one, as it will be the outcome in the auction mechanism. Remember that total consumption in this case is $x^*_A$. In the competitive equilibrium
with equated marginal rates of substitution, the two parties trade off good $A$ and good $B$ in the ratio of $\kappa$, where

$$\kappa = \tau - \gamma x^*_A. \quad (7)$$

Consider a competitive equilibrium where each transfer of 1 unit of $q_A$ to the $d$ type is compensated by a transfer of $\kappa$ in $q_B$ to the $d$ type. Then all available supply of $B$ is exhausted when

$$q_B(d) = \frac{\mu Q}{n} + \frac{(\delta - 1)d\kappa}{2}, \quad (8)$$

and

$$q_B(d) = \frac{\mu Q}{n} - \frac{(\delta - 1)d\kappa}{2}. \quad (9)$$

Intuitively, this outcome has the feature that the food poor receive more of the staple good, $A$, but the food rich receive more of the luxury good, $B$, to compensate them for this, where the “rate of exchange” is given by $\kappa$.

**Corner Solutions:** This equilibrium involves both types receiving positive $q_i$. However, when supply of food is limited, corner solutions arise, where one party (and potentially both) receive all of the available $q_i$. They arise for one of two reasons: either there is not enough supply of good $A$ to allow marginal utilities to be equated, or there is not enough good $B$ to compensate the food rich to give up good $A$. These details are described in the Appendix.\(^\text{23}\)

### 5.3 Competitive Equilibrium Through Equal Incomes and Symmetric Redistribution

Having defined competitive equilibrium for the interval game, we now show how that equilibrium is a Bayesian Nash equilibrium of the game through allowing food banks to bid on lots of food each period. Consider the game where (i) $s_{11} = 1$, $s_{It} = 0$ for all $I > 1$, so that all food banks begin with one unit of shares and are not added to or subtracted from at the beginning of the next interval, and (ii) $r_{it} = \frac{1}{N}$ for all $i$ and $t$. Call these respectively “initial equal incomes” and “symmetric redistribution”.

**Proposition 1** The competitive equilibrium of the interval game above is an equilibrium of the bidding game with equal initial incomes and symmetric redistribution. In this equilibrium, each food bank bids $b_i = p_i$ until it reaches its equilibrium competitive

\(^{23}\)One natural case for a corner solution is when there is not enough food to equate marginal valuations, $\frac{\mu Q}{n} < (\delta - 1)d$. All else qual this leads to the food poor receiving $q_A = Q$. However, this requires that there is not enough good $B$ for the $d$ type. If there is not, then $q_B = \mu Q$, and the food rich must also be offered good $A$ to induce them to reveal their type truthfully. Finally, for a range of values of $\mu$, there is complete segregation, where the food rich get all of $B$ and the food poor get all of $A$.  

22
allocation and then bids \( b_i = p_i - \epsilon \), for \( \epsilon \) small. At the end of each interval, all food banks have a share balance of 1 and purchase \( q_i(d) \) in (5), (6), (8), and (9).

This shows how it is possible to implement the competitive equilibrium of that interval. As there are no links in the fundamentals across intervals - as there is no transitory noise for example - the repeated competitive equilibrium of the interval game is the competitive equilibrium of the overall game.

The full details of the implementation through prices is described in the Appendix, but it is useful to consider the case where both types buy both each kind of food in equilibrium. In this case, consider equilibrium prices given by

\[
\frac{p_A}{p_B} = \kappa, \tag{10}
\]

where \( \kappa \) is as in (7). With these relative prices, the desired level of quantities are given by (5), (6), (8), and (9), as required. Two issues remain: (i) can they afford these quantities with their budget?, and (ii) can they implement it by bidding?

First, to guarantee budget balance, it is necessary that \( p_A \bar{q}_A + p_B \bar{q}_B = 1 \), and \( p_A q_A + p_B q_B = 1 \), subject to \( \bar{q}_A + \bar{q}_A = Q \), and \( \bar{q}_B + \bar{q}_B = \mu Q \). Substituting from (10) yields equilibrium prices as

\[
p_A^* = \frac{1 - \frac{\mu Q - \kappa d(\delta - 1)}{\mu Q + \kappa d(\delta - 1)}}{\Omega} \tag{11}
\]

where \( \Omega = \left( \frac{Q + (\delta - 1)d}{2} - \left( \frac{\mu Q - \kappa d(\delta - 1)}{\mu Q + \kappa d(\delta - 1)} \right) \right)^2 \). and

\[
p_B^* = \kappa p_A^*. \tag{12}
\]

This shows that absolute prices can be designed such that the market clears each interval while retaining relative prices. Finally, note that at these prices, all food banks find it optimal to bid \( b_i = p_i \) until they reach \( q_i \) in (5), (6), (8), and (9), and to subsequently bid slightly less. With those strategies, all parties receive their competitive allocations. The corner solution cases are derived similarly and shown in the Appendix.

This Proposition illustrates the Second Welfare Theorem in this setting, with competitive equilibrium implemented by budgets of equal income. Of course, it relies heavily on the repeated nature of the bidding within an interval (and more generally across intervals), where a food bank does not worry about bidding and losing, as there will be an auction tomorrow from which they may win.

### 5.4 Testable Implications

The purpose of the framework is to identify measurable implications of allowing choice over the previously used assignment mechanism. Under the old system, each food bank was assigned an equal amount of each of the two goods. To allow for supply
responses, let the supply of food under the old system be $Q'$. Then the welfare of the old system per food bank was $U = (\tau + \mu)\left(\frac{d+Q'}{2}\right)Q_n - \frac{\gamma}{4}\left((\delta + Q_n)^2 + (d + Q_n)^2\right)$. The per food bank utility from the competitive equilibrium depends on whether outcomes are interior or at a corner. For illustrative purposes, consider the case where both types purchase both goods. Then the utility from the Choice System is given by $U^* = (\tau + \mu)\left(\frac{d+Q}{2}\right)Q_n - \frac{\gamma}{2}\left(\frac{d^2}{2} + \frac{Q_n^2}{2}\right)$.

The benefit of the Choice System over central assignment then given by

$$\Delta U = U^* - U = (\mu + \tau - \gamma)(1 + (\delta - 1)d)\frac{Q - Q'}{n} + \frac{\gamma d^2(\delta - 1)^2}{8}. \quad (13)$$

The first term is the value of changed supply (including the diminishing returns piece captured by the $\gamma$ term), which is easily measured and intuitive. The second part measures the benefit of improved allocation of goods from the use of choice, but depends on variables that are not directly observed, as food richness is unknown. Let $\eta = \gamma \frac{d(\delta - 1)^2}{2}$ be the return from better assignment.

Observed prices and quantities can be used to measure a correlate of these welfare gains. To see this, note that the total quantity of food obtained $q(D) = q_A(D) + q_B(D)$ is given by

$$q(d) = \frac{(1 + \mu)Q}{n} - \frac{(\delta - 1)d(1 - \frac{p_A}{p_B})}{2} \quad (14)$$

and

$$q(d) = \frac{(1 + \mu)Q}{n} + \frac{(\delta - 1)d(1 - \frac{p_A}{p_B})}{2}. \quad (15)$$

Then as $Var(q) = ((\delta - 1)d(1 - \frac{p_A}{p_B}))^2$, this implies that

$$Var(q) = \eta \frac{\gamma}{8(1 - \frac{p_A}{p_B})^2}. \quad (16)$$

As a result, the value of better allocations from choice can be directly measured from the variance in average quantities. Of course, this is subject to a constant that cannot be directly observed (note however that relative prices can be observed and that $\gamma$ is the responsiveness of demand to relative prices, so could potentially be estimated as an elasticity), but we can at least impute welfare gains as increasing in this variance measure.

Of course, prices are the dual of quantities, and at times below it is simpler to work in price space. In steady state, $Eq(d) = \frac{1}{Eq(d)}$, so that there is a one to one mapping between measuring the variance of prices and the variance of $\frac{1}{Eq(d)}$. Some of the results offered below on the return to the market will be measured in price space.

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24This does not allow savings. In a steady state where the savings rate is $s$, $Eq(d) = \frac{1-s}{Eq(d)}$. 

25
To summarize, in this case where the both the food rich and the food poor buy both kinds of goods, the value of the market is linear in either the variance of average quantities or the variance of the inverse of average prices paid by food banks. It is also straightforward to show - and shown in the Appendix - that when the market is at a corner solution, the return to the market is not linear in these variances but rather is linear in the standard error so once again a monotonic relationship arises.

The Composition of Food: A simplifying feature of the model above is that food banks vary in their endowments, but the variation is vertical, in the sense that some have more of everything than others do: the food rich have a proportion $\delta - 1$ more of each good than does the food poor. Yet an important potential benefit of the Choice System is that it allows food banks to react to variation in the composition of their food rather than its overall level: so for example, a food bank may transitorily have a lot of dairy products but little cereal.

Here we consider the thought experiment where food banks also vary on the composition of their food, holding richness constant. Holding “wealth” constant implies that when a food bank has more of $A$, they have less of $B$, where the amount “less” is determined by relative prices. The endowment of goods $A$ and $B$ are now $D_A$ and $D_B$ but where

$$D_A = D + \lambda,$$  \hspace{1cm} (17)

and

$$D_B = D - \frac{p_A}{p_B} \lambda.$$  \hspace{1cm} (18)

Varying food in proportion to its price level is simply done to consider sources of variation that abstract from income effects. For simplicity, think of the distribution of $\lambda_i$ for food bank $i$ as binary: $\lambda_i \in \{z, -z\}$, with equal probability and independently distributed across food banks. (More general distributions do not affect the logic below.) Assume that the number of food banks is large enough that this does not affect the aggregate quantity of food.

Again consider the case where $Q$ and $\mu$ are large enough that the marginal rates of substitution are equated for both goods. In the Appendix, we show that

$$\Delta \tilde{U} = \Delta U + \frac{\gamma z^2}{8},$$  \hspace{1cm} (19)

so that the choice system offers an additional benefit through smoothing compositional shocks to supply, where again the benefit is parameterized by variance of average quantities by food bank.

Welfare Gains from Outside Endowments: Food banks obtain food from other sources: permanent variation in $d$ generates much of the welfare gains below. In the empirical section below, we will attempt to test for this, by identifying how greater outside endowments affect the kind of food bought. To address this, consider the
impact of a food rich bank receiving more food. This clearly increases its own welfare. Yet it is also increases the welfare of the food poor through changing relative prices, as aggregate demand for good $A$ falls. Specifically if $U(d)$ is the utility of the food poor $d$ type, then

$$\frac{dU(d)}{d\delta} = -\frac{dp_A}{dp_B}(\delta - 1)d = \gamma \frac{\delta + 1}{n} (\delta - 1)d = \frac{(\delta^2 - 1)d}{n} > 0.$$  \hspace{1cm} (20)

Below we show how one measure of increased endowments - more blue pounds given to a food bank - affects equilibrium choices.

5.5 Extensions

The framework offered above has a number of limitations which are addressed below.

A more nuanced view of the old system In the analysis above, we have simply posited that the old allocation system offered an equal number of pounds to all food banks per client. This allowed us to measure the value of the Choice System by the variance of either quantities or prices. In reality, there are two reasons why this relationship may not hold (when more data arrives, this will be empirically tested). First, food banks can turn down food, and may do so even if it means they go to the bottom of the line. To the extent that the food rich turn down food more often, the old system may have an implicit redistribution mechanism. Second, food banks share food. A food bank that receives a truckload of carrots that it cannot use effectively may offer it (or part of it) to another food bank, often with the understanding that the receiving food bank will reciprocate the favor down the line. This will improve allocations relative to the benchmark offered above. Of these two, only the first can be tested, as we have no information on this kind of informal sharing.

This changes the analysis above in one simple way. With linear marginal willingness to pay, the welfare gain through better allocations in the Choice System are no longer parameterized by $\text{Var}(q(D))$ but rather $E(\nu^2)$, where $\nu$ is the difference in average quantity by a food bank between the Choice System and the old system.

Maroon pounds So far we have assumed that net supplies to a food bank must be non-negative. Yet the market allows food banks to place $d$ on the market. This is not frictionless for one very important reason - they currently have that food in their warehouses, and do not have to pay transportation costs, while yellow pounds are more symmetric in that way. As a result, there is a reason to imagine that the supply of Maroon pounds will not equilibrate the marginal valuations. However, if these frictions are low enough, the market will avoid the corner solutions above.

Diminishing Returns to the High Quality Good The model above assumes that the returns to the high quality good are linear, so that - for example - the
value of chicken is independent of who gets it. The assumption of the absence of diminishing returns to this good is for simplification, to allow simple closed form solutions. Consider, for example, a case where the utility function is

$$U(x_{Alk}, x_{Bik}) = \tau x_{Alk} - \gamma_A \frac{x_{Alk}^2}{2} + x_{Bik} - \gamma_B \frac{x_{Bik}^2}{2},$$

(21)

where $\gamma_A > \gamma_B$. In this setting, the higher quality good also suffers from diminishing returns, but at a lower rate. One simplification of the model above, is that equation of marginal rates of substitution also implies equation of marginal utilities across the two types. This is no longer true, and instead the competitive equilibrium where both types purchase both goods is now given by

$$\frac{p_A}{p_B} = \frac{\tau - \gamma_A(\delta d + q_A)}{1 - \gamma_B(\delta \mu d + q_B)} = \frac{\tau - \gamma_A(d + q_A)}{1 - \gamma_B(\mu d + q_B)}. $$

(22)

This retains the central feature of the model above, where if $\gamma_A > \gamma_B$, it will be the case that the food rich gravitate towards good B in the sense that $\frac{q_B}{q_A} > \frac{\tau}{\tau}$.  

Other Efficient Rules

It is worth pointing out that there are many ways in which this outcome could be implemented within an interval period. For example, at any time period $t$ in an interval, let there be $n_it$ remaining bidders for good $i$. The mechanism could allocate $\frac{n_it}{n_i}$ to all remaining bidders, or it could assign all of the remaining quantity to a smaller number of bidders so long as it does not exceed the equilibrium quantity. One appeal of this mechanism is that it allows for indivisibilities, as transportation costs realistically result in an economy of scale up to say 40,000 pounds of food.

Second, the principal has other redistribution mechanisms that could generate competitive outcomes. One would be to choose $R_{ijt} = 0$ so the funds are never redistributed during an interval, but where everyone is given a new budget of 1 at the beginning of each interval. This is an outcome of the deterministic setting used here, where each food bank knows it has exactly the right amount of money to last the interval. Symmetric daily reallocation can be beneficial for a number of reasons. For example, suppose that there was an unexpected positive supply shock on a given day of good B. Without daily reallocation, by buying the good the remaining supply of shares would fall, and so future prices fall, even though there is not demand reason for prices to fall. By contrast, with daily reallocation, future prices remain unchanged, as one would wish as marginal valuations have not change.  

25With more general utility functions, the auction generates a competitive equilibrium under the usual convexity assumptions, but it not possible to generate closed form solutions for the value of the market. Let the utility of a food bank be $U = U(D + q_A, \mu D + q_B)$ where $U$ is increasing and concave, and where the goods are weak substitutes. Then ignoring the corner solution cases above, the competitive equilibrium generated by these price taking agents is characterized by

$$\frac{U_A'(\delta d + \mu \delta d + q_A)}{U_B'(\delta d + \mu \delta d + q_B)} = \frac{U_A'(d + q_A, \mu d + q_B)}{U_B'(d + q_A, \mu d + q_B)} = \frac{\tau_A}{\tau_B},$$

where $\tau_A + q_A = \frac{q_B + \tau_A}{\mu} = Q$.  

26Continuous topping-up has at least two other advantages. First, it avoids the kind of stock out
**Saving and Credit**  The model above allows the static replication of the interval equilibrium: while food banks move their shares about within an interval, they do not move them across intervals. This is because there are no transitory shocks that they do not need to smooth. In reality, food banks do smooth over time. They do so in two ways. First, they access credit, which they pay off over the space of a couple of months say. In the Appendix, we describe the role of credit in the model in a setting where agents do not save but use credit to smooth consumption. A conceptual difference here from the results above is that the agents privately know their own endowments, and have an incentive to claim that they are too poor to pay off their debts today, but rather would like to push it into tomorrow. As a result, distorted repayment rules may be needed. Using the rule offered through the Choice System, the model in the Appendix offers a welfare implication where welfare gains are also quadratic in credit use. The second way in which food banks smooth is through precautionary savings. A model with such savings has not yet been computed for this setting, but is on the agenda for a future draft.

**Information**  There are two assumptions in the price taking behavior above: that all food banks take the price as given, and that they all know what that price is. One reason why the Choice System could have a downside is if food banks hold different beliefs about equilibrium prices. As an example, if the small food poor food banks thought prices were much higher than do the larger food banks - and bid accordingly - then the market could induce inequality, as you pay what you bid in this first price auction setting.

There are a number of responses to the possibility of food banks making errors in estimating prices. First, the website offers a history of prices for similar goods, so it is relatively easy to see what the ballpark price is likely to be for a given load. Second, there are roughly 60 auctions a day, for 200 days a year, so that the food banks quickly developed a lot of experience bidding. This is far from a setting where auctions are infrequent, where such misperception would likely arise. Finally, this is ultimately testable, by seeing whether there is any systematic variation in prices paid by food banks for food of a given type and location.\(^\text{27}\) As more data becomes available, this exercise will be carried out.

problems that arise in many settings, where people run out of money before the next pay check arises. This would take the form of budget constrained agents who cannot afford to bid on some items. Time becomes more continuous in this setting. Second, it has a psychological advantage of each food bank seeing itself as the seller of the good, so that whenever a food bank buys a desirable item, the other food banks immediately benefit. This would be especially so in a setting where say rarely an extremely desirable good comes along, and trades for a very high price. Rather than a food rich buyer resulting in jealousy from the other food banks, they would see themselves of the beneficiaries of such a high priced sale.

\(^\text{27}\)A potential concern is that is may not reflect true outcomes early on after the changeover, when players were learning how to bid. One indication of this is large dispersion in prices in the first couple of years: for example, 12% of prices were negative in the first two years, and over 50% of prices were non-positive in the first year. Similarly, early on few food banks accessed credit. However, there is
Finally, it is worth pointing out that errors per se do not necessarily generate a problem for the outcomes above. For example, in the case where all food banks make a symmetric transitory error in prices (where each believes temporarily that prices are too high or too low), the distortion from errors is small if the interval is sufficiently large, as the errors even out over the interval. This is shown in the Appendix.

6 Outcomes

In this section, we outline the outcomes of the change to the Choice System. Before providing the relevant data, it is worth nothing that the transition has been perceived as a success by its participants. Food banks are engaged, bid frequently, and largely extol the merits of being able to choose what they want over what they are told to take. This has benefits both to overcome transitory shocks to demand and supply but also by allowing them to sorting on the spectrum of quality-quantity dimension. Supply of food has increased, and many of the safeguards that were put in place have fallen into benign neglect due to lack of use.

The data offered come in a number of forms. First, Feeding America monitored the engagement of food banks and their behavior seven months after its introduction, so we being with some data during that time period in order to garner some initial responses. Second, Feeding America has offered the author considerable additional data. The data used here come in two forms. First, for some exercises, aggregates will be provided both before and after the change to the choice system. Those after the changeover derive from aggregating data on 64,570 auctions from 2005 to 2011. Second, for the analysis at the individual food bank level, for data availability reasons, this focuses on all 12,322 auctions that occurred in 2008. As more data becomes available, these food bank level exercises will be extended to surrounding years.

All food banks became quickly engaged in the bidding process. Within the first 7 months, 97% of food banks won at least one load. Over this period, each item received a mean of three bids. The range was from 1 to 29 bids. No food bank has chosen to delegate bidding control to Feeding America, except for cases where the director is on vacation for a short period. Finally, the Fairness and Equity Commission has never met, as there has not been any demand from a food bank for a review of their situation: as can be seen below, this is likely because the new system has implied that food is always available to a food bank that has access to transportation.

Under the old allocation mechanism, Feeding America treated a pound as a pound, and its objective was to offer each food bank an equal number of pounds per pseudo client. This is a reasonably efficient allocation mechanism if food banks treat all pounds equally. A natural ex post measure to identify if this is reasonable is to considerable stability in these measures now: the fraction of non-positive prices remained stable at 20% from 2008 to 2011, while the use of credit is also stable over that time period at 12% of the winning bids. This would suggest that bidder behavior has converged.
measure whether the bidding data reflects the relative indifference of food banks to issues other than the weight of food being attained.

We measure this in Figure 2 by showing the dispersion of winning bids (prices) for 2008. This does not condition on the kind of food, its location, etc. Figure 2 shows enormous variation. The average price level - meaning the number of shares per pound - was 0.17, so that on average food banks were receiving six pounds of food for each share offered. As one measure of the dispersion, the standard deviation of the distribution is 1.01, three times the mean. Almost thirty per cent of all offerings sell for 0.05 shares of less, so that a food bank can get 20 pounds of food for each share it spends. Yet at the right hand tail of the distribution, 25% of loads sell for 0.3 shares or more, and in 10% of cases, the buyer gets two pounds of food per share or less. As one extreme observation, in 8% of cases the buyer receives less than one pounds of food per share spend, while in 30% of outcomes, the buyer received 100 pounds of food per share, or more.

This large variation points to significant problems with the old system simply through treating a pound as a pound, even if all food banks were identical. Consider the following simple - if caricatured - example. Two food banks want chicken and carrots, but each likes chicken a lot more than carrots. There are two loads of each. An assignment algorithm that focuses on pounds received rather than one that weights quality will oftentimes give one food bank the chicken twice and the other the carrots twice. The price data above show that the distortions from this outcome - whether through diminishing returns, spoilage, or simple fairness - are potentially large, as the revealed preference from the price data shows such variation in willingness to pay.

A primary driving force of the variation in prices is the kind of food that is being offered: foods with higher nutritional value, lower spoilage - either through food rotting or not being used by end clients - and ease of transportation, likely have an advantage over other goods. However, before considering how prices vary by different kinds of food, it is worth considering the supply side: what is offered. The distribution of offered goods in 2008 is given in Figure 3. There is a large variety of products offered to the market: in essence, any kind of food can show up, as well as non food items such as health care or beauty products. Yet it is worth noting that almost 40% of loads are produce, snacks, or beverages. As will become clear a little below, two of these are problematic for food banks. First, beverages - usually carbonated drinks - typically have little nutritional value (though are often very valued by clients), and are expensive to transport. Second, produce is in such abundant supply that there is little willingness to pay. In addition to this, much produce needs refrigeration and is often close to expiration by the time it is donated to the system. By contrast, many of the most desired items - meals and meats for example - are not abundant, with meat and dairy jointly accounting for only 6% of loads.

Figure 4 shows average prices by kind of food. Loads vary by many characteristics - location, transportation costs, likely spoilage, and so on - but the primary source of variation in their desirability is the kind of food. Figure 4 shows variation in
willingness to pay by food type. The numbers here have been normalized such that the median good has a pseudo price of 1, so the numbers here reflect price relative to average price. At the lower end of the distribution, produce (marked as “fresh” in the language of the offerings) sells for 2% of the price of the average good, and beverages trade for 3%. In simpler terms, a food bank can get 50 pounds of produce for a single pound of the average good, or 30 pounds of beverages. Remember from the Figure 3 that these two categories represent almost a third of all offerings (at least in 2008), so this points to a large fraction of offerings to the system that the (marginal) food bank is close to indifferent about obtaining. By contrast, prices for rice, pasta and cereal are roughly three times the price of the median good.\footnote{All else equal, these (though desired) are not as desirable as meat or meals, but the latter requires refrigerated trucks, which are considerably more expensive, so that the willingness to pay for these is roughly twice the average.}

As alluded to above, there are many potential benefits to allowing food banks to choose their food. One of these is the role of markets in smoothing transitory variations in preferences, as manifested in the modeling section of the paper under composition of food.\footnote{Such transitory variation most likely arises from other inventory of food. A food bank already has yoghurt, and needs no more.} Under the old system, it could be assigned more yoghurt (or more plausibly a product that is a substitute for it, either in the demands of it clients or through refrigeration capacity constraints), while a market allows that food bank to instead purchase food that is not a close substitute.\footnote{If all goods were equally valued by food banks, such distortions would be lower than in a setting where there is great variation in prices. As an example, giving a food bank excess meat is costly if they cannot use it, as the valuation of other food banks is so high. As such, the variation in prices directly reflects the value of allowing choice to smooth these transitory shocks.}

A second benefit of the market is to allow food banks to sort on the quality-quantity dimension. Food banks are not equal in their endowments of food: some are food rich and some are food poor. Those who are food rich already may already have enough of the staples such as produce, beverages, tinned vegetable or fruit, and instead may prefer to move up the quality-quantity budget line to only acquire higher priced items such as chicken or cereal. By contrast, the food poor can take advantage of this by acquiring larger quantities of the staples at lower prices.

The framework above focuses on these benefits through measures of dispersion to reflect welfare gains, specifically dispersion in behavior across food banks in the average quantity and quality of food attained. These came in the form of either dispersion of quantities or prices. For data reasons, it is simpler at the moment to measure dispersion in prices.\footnote{This is because quantities need to be normalize by goal factor, and the data currently available is goal factor in 2015, not 2008 as would be desired. Such normalization is not needed for prices. We are aware of course of the issue that measuring the variance of the inverse of prices is not the same as the inverse of the variance of prices. However the dispersion is so great that it is likely to swamp any of these Jensen’s inequality or existence issues.} Such dispersion in prices is given in Figure 5. This measures the average price paid by a food bank for a pound of food for 2008. As a
benchmark, under the old algorithm, each food bank would have received 3 pounds of food for each share. (Of course, shares were not in existence then, so this is simply dividing the number of pounds of food in 2008 by the outstanding stock of shares.) These data show extraordinary sorting on the quality dimension. Among those who restrict purchases to the high end good, 15% of food banks pay at least twice as much as average for their goods, receiving no more than half the number of pounds that they would have received. By contrast, there are a large number of “bottom feeders” who are receiving vastly more food than under the assigned outcome: 15% of food banks receive three times as much food and 4 food banks are receiving 10 times as much food.

Throughout the deliberations in setting up the Choice System, much time and effort was spent in ensuring that those food banks that are food poor or small would not be harmed by the market system. The committee spent a large amount of time deriving a series of explicit safeguards so that food banks would not be significantly disadvantaged by the changes. Two stood out: the Fairness and Equity Committee, and the ability by food banks to delegate bidding to Feeding America. As mentioned above, no food bank delegated bidding to Feeding America. More striking is that the Fairness and Equity Committee has never convened, due to the widespread satisfaction with the outcomes of the Choice System.

In order to better understand how smaller food banks have fared, Table 1 provides regression results predicting which food banks on average choose quantity over quality. To do so, we carry out two exercises. First, much of the discussion of food richness concerned the size of the food bank: the caricature was that Los Angeles has tons of other food, yet rural West Virginia has very little. The first column of Table 1 predicts average price paid by the goal factor of the food bank. This has a degree of measurement error as this is the 2015 goal factor, not 2008. (As historical data on goal factors becomes available to the author, this will be changed appropriately.) To the extent that poverty levels across the US have changed across areas over the last decade, these involve a degree of mis-measurement, yet - to put it bluntly - rural Mississippi remains rural Mississippi and Rhode Island remains Rhode Island. Goal factor closely reflects the size of a food bank, and the regression shows that larger food banks sort into higher quality foods, leaving the lower quality foods for the food poor. As a result, one of the major benefits of the market for the smaller food banks is that it has rendered vast quantities of staple foods available for those food banks, and available at low prices. To a first approximation, if a food bank has access to a truck, food is always available. Of course, they do not get so much high quality food, but that is their choice.

The central idea of sorting by food richness is that when a food bank has other food, it moves up the quality distribution. To provide a more direct test of this, note that Feeding America offers blue pounds to food banks, where a donor specifies a food bank that the donation must go to. Table 1 also predicts average price paid by the blue pounds offered (normalized by goal factor), and shows that the more pounds
that are offered to it through direct donations, the more the food bank moves up the quality distribution.

If food banks always spend their entire budgets, then quantities are simply the inverse of prices, and the model focused on dispersion in prices. Table 2 examines the relationship between the log of the number of pounds of food attained and the goal factor of the food bank in 2015. Under the objectives of the old system, the coefficient on this relationship would be 1, as the objective of the old system was to offer all food banks the same number of food per pseudo client. Any coefficient below 1 suggest the high Goal Factor food banks sort into higher quality food, and vice versa if the coefficient is below 1. From the first column of Table 2, a increase of 1% in the Goal Factor results in only a 0.158% increase in pounds of food, suggesting a sorting into quality once again. However, here the measurement error in Goal Factors is important, as a 2015 measure is not the measure of need used by Feeding America. However, to show that it likely reflects such sorting, the second column predicts log pounds of food in 2004 by the Goal Factor in 2015. If all that was being picked up in these regressions was measurement error, then the regression estimate predicting log pounds in 2004 would be noisier than in 2008, and have a lower coefficient. However, the coefficient is 0.45 and statistically significant. (The fact that it is not 1, of course, either points to some measurement error, or some seepage in the old algorithm from offering equal pounds for each pseudo client.) That the regression has better predictive power for 2004 than 2008 provides more evidence of food banks sorting on the quality-quantity dimension, allowing the market to better sort its consumers.

A second way in which the playing field was leveled for the smaller food banks was to allow them to access credit. As noted above, this is relatively short term credit, as the food bank must repay with half its allocation until its debts are cleared. Figure 6 shows the use of credit over time. In the early stages of the Choice System, the use of credit was relatively rare, with only 3% of winning bids involving the use of credit shares. However, over time food banks have learned to like credit, so that from 2008 to 2011, the fraction of winning bids has remained stable at roughly 12%. Remember that only about half of all food banks qualify for credit, so that among those food banks that qualify, almost a quarter of all the winners use credit. Also note, however, these these food banks tend to purchase relatively inexpensive items, so normalized by prices this would be a lower share of wins.

The second way in which the smaller food banks could leverage the market was through the use of joint bidding. At the time of writing, no data has been provided on its frequency, but will be provided when it becomes available. A further example of the dissipation of concerns for smaller food banks is that the system has changed in the last few years such that now negative shares are possible on the first day that a product is offered. Initially this was not done for fear that access to these bonus shares would not be equal if the smaller food banks check offerings and balances less frequently than the larger ones. As this is no longer a concern, the desire to quickly move this product has taken precedence.
Under the old system, it was difficult to place “hard to move” product, to use the parlance of Feeding America. Arms were twisted in order to keep donors happy. An innovation of this market was to allow negative prices, where food banks would be paid to take certain loads. (To my knowledge, this is the first example of allowing negative fake money prices: for example, course assignment problems for MBA students do not pay those students for taking classes from the least desired professors!) Figure 7 shows the frequency of such negative prices over time. These data show a striking decline in the need to bribe food banks into taking food. In the first two years of the Choice System, 11% of loads involved the need for “bonus” shares, yet this has declined considerably to only 4% in 2010 and 2011. This decline likely reflects two issues, one external and one related to the system. It took food banks time to learn how to bid, and the market has become more liquid over time, reducing the ability of food banks to bid negative shares and win.

There is one important caveat to only considering negative prices, which is that the Choice System does not allow negative prices for produce. (This was a decision made because produce is so abundant in the system that there was a concern that on some days the average price paid could be negative, which would result in the reallocation of shares at midnight reducing balance from one day to the next, which was seen as politically infeasible.) Figure 8 extends the analysis above by showing the frequency of non-positive prices. Similar to the last figure, a large decline can be seen here, from 45% of all loads in 2005 and 2006 to a stable 20% from 2007 to 2011. This again reflects the greater liquidity of the system, but in addition reflects a change in bidding strategies by some food banks. Over time, some food banks seem to have worked out how to bid slightly greater than 0 in order to beat other food banks bidding 0. (One food bank appears to have come up with up with the “magic number” being to bid 7 shares for a load that is typically 40,000 pounds!)

In the context of non-positive prices, note that the old allocation system involved considerable discretion by Feeding America. Most food banks accepted that this was done in the best interests of feeding the hungry, yet there were concerns about whether some food banks were being offered better food than others, perhaps based on location or contacts. A major benefit of the Choice System is its transparency: prices are often zero or negative, yet there are few complaints about this as anyone could have bid on them.

These data would seem to suggest that the use of negative shares (or very low positive bids on produce) have eased this ability of Feeding America to facilitate donor relations. However, some auxiliary data would suggest a problem may remain. A closer look at the data for these cheap items for 2008 shows a number of issues. First, produce sells for its minimum value 26% of the time. Second, remember that the maximum amount of negative shares is -2000. Conditional on negative shares being used, the average price paid is -1803 in 2008, once again suggesting strongly that the lower bound is hit frequently. Of those 8.5% of cases where negative shares arose in 2008, a little less than a third (2.5%) were beverages. These data suggest it
remains the case that even with these low bids, a considerable amount of produces is simply not desired. If no bids arise in the feasible range, the donations are turned down or Feeding America resorts to twisting arms again. If these bounds are set to reflect the shadow value of these donor relations, then this is of course the efficient outcome, but it remains unclear if some donations should be encouraged beyond the current low levels that are used.

An important final value of the market to assign goods is its ability to increase supply of food to the system. As alluded to above, this can arise either through (i) donors valuing the fact that the food is more likely to be used efficiently, (ii) Feeding America being more likely to accept donations as the Choice System is so liquid, or (ii) food banks placing Maroon pounds onto the Choice System. Figure 9 provides some data on this. This gives the total number of yellow pounds in the system. The number of pounds was relatively constant at 200 to 220 million pounds before the changeover, yet immediately the number of pounds in the Choice System was about 50 million pounds higher immediately afterwards. There was a small decline over the succeeding years, but this largely reflects the impact of the financial crisis on donations.

This figure significantly underestimates the impact of the Choice System on supply for a number of reasons. One is the impact of the financial crisis on supply, as alluded to above. A clearer picture may be possibly seen by considering a narrow window around the time of its introduction. While the supply of food to the system was relatively constant before the change to the Choice System, the number of pounds of food on the system rose by 50 million pounds in the first seven months after its introduction. Specifically, after 7 months, 192 million pounds of food had been “sold” through the new allocation system, compared to roughly 140 million pounds by that time in a normal year.

The second reason for an underestimate is that these data only show the number of pounds on the Choice System itself. Yet, as pointed out above, for some product that is hard to move (mostly produce) Feeding America directly approaches food banks to take it rather than put it on the market. (The market can take two days for pickup, so for food close to expiration it makes more sense to directly place the food if possible.) Data provided by Feeding America on the total number of pounds in the system is given in Figure 10. It shows total pounds in 2006 to 2008 averaging 340 million pounds rather than the 270 pounds that are allocated through the auction mechanism in Figure 9, suggesting a much larger increase in supply.

Some of this difference is Maroon pounds. These are given in Figure 11. These add approximately 12 million pounds to supply each year from 2005 to 2012. Not only does this increase supply of food to the Choice System, but it also increases quality. On average, maroon pounds sell for about twice the average price per pounds on the system. As a result, if one adjusts for quality, the impact of these Maroon pounds would be closer to 25 million pounds.

It is difficult to calibrate whether the amount of Maroon pounds is high or low at
There are at least two reasons why this is probably so. First, these are typically goods that already are located at the donating food bank, and so there is a clear wedge between the value of the goods to the donor and to any recipient, which has to transport it. Second, this option is arising in the shadow of a system where food banks already share with each other, and an enunciated concern with the Maroon pounds by some food banks is that it is seen as “unfriendly”, to gain shares at the expense of other food banks, when they could simply be given to someone. A reasonable interpretation of the supply of Maroon pounds may be that they are used when there are few takers in the usual network through which a food bank shares, and so it is an alternative to the goods not being efficiently used at all.

Another interesting avenue to explore is to see how the Choice system has affected the quality of food overall, not simply to measure it through the number of pounds. Theoretically, it is not clear how quality will be affected. First, knowing prices will help Feeding America solicit donations: as food banks value peanut butter so much more than produce it may orient their solicitation efforts towards those high quality goods. All else equal, this would increase quality. Similarly, the average quality of maroon pounds is much higher than the average good on the system. Yet this must be balanced against the donation decisions that Feeding America makes: which offers will they accept? One feature of the Choice System is that the market has become more liquid and product easier to place. This is not a concern for placing chicken or peanut butter, as someone would always raise their hand for those products. Instead, it is likely that the liquidity of the system makes Feeding America more likely to accept marginal quality donations: tinned vegetables for example. If this effect is dominant, then average quality could fall.

No data are currently available before 2005 on the quality of food on the system, so at the moment we cannot answer this question. However, to get a sense of impacts after the changeover, we have carried out the exercise of estimating quality changes between 2007 and 2008. (This will be extended to other years.) The average price (weighted by load) in 2008 was 0.328 shares per pound, with the relative prices being given in Figure 4. In order to estimate changes in the quality of food between 2007 and 2008, we can attach the product level prices to each offering in 2007, and then aggregate to an overall price level. Any differences in price level then reflects a change in quality between these two years. Carrying out this exercise shows an average price of 0.335 in 2007, so that the quality of food reduced by about 2%, suggesting significant stability in quality offerings. In time, this methodology will be extended to other years, hopefully including before 2005.

This market design system is unusual in many ways, not the least of which is the possible need to rebalance the supply of shares over time. As described in the main body of the text, an objective of the supply of shares was to aid transparency through keeping prices constant, all else equal. Figure 12 shows the average number of shares paid for a pounds of food over time. It has remained relatively constant.
at 0.15 throughout these six years, but with one exception. In 2008, the price of a pound of food jumped 30% to 0.21. We do not see this as a failing of the share supply system: instead, it represented the kind of very unusual event where prices should change. Specifically, this picks up the large impact that the financial crisis had on the food banking industry: demand rose, and supply fell, so that prices for goods rose as economics would predict. This is not a case where we believe that the supply of shares should change to eliminate this, as this is the kind of inter-temporal shock that should be reflected in higher prices.

One possible point is worth making here, however. A price rise for a good implies that the value of that good increases relative to some alternative. So if the price of a TV rises, it implies that the value of TVs relative to alternatives goes up. Yet remember that shares have no value outside the system, so what is the alternative? The most natural alternative is purchases in the future, where food banks changed the timing of their purchases. One way in which this arose was the use of credit, as can be seen in Figure 6. Yet credit is so short term in the Choice System (it is paid off typically in a month) that it likely has no effect on aggregate prices. Instead, the likely effect of the financial crisis was to run down savings: balances held by the food banks. Furthermore, it is typically the food rich food banks that hold the most balances (this is an assumption as data on share balances are yet to be forwarded to the author). Consequently, the financial crisis may have had an oddly regressive outcome where the food rich - who normally do not bid on staples - entered the market and bid on a range of goods that would be otherwise left to the food poor. At the moment, this is merely a hypothesis, which will be tested with more data.

7 Conclusion

Seen from afar, the idea that a specialized currency could be used to allocate food more efficiently while simultaneously respecting the relative level of need in an area may seem straightforward. However, despite the conceptual simplicity of the solution, it is worth pointing out that it is very rare to observe these kind of “Monopoly money” solutions being used to allocate resources in real world settings. There are, of course, a large number of barter markets which involve the trading of scrip, but these are sparse and characterized by rampant illiquidity. Indeed, as one of the only examples offered of such mechanisms is bidding for business school courses, this surely points to the limited empirical importance of these kind of solutions.

Perhaps the rarity of these kinds of interventions is because there are not so many cases where one can create budgets in non-traditional currencies to reflect consumer preferences. Alternatively, it may be that it is not the broad conceptualization of the problem that generates success, but rather the myriad of small details that gets it over the line. Here these details involved a series of tweaks - simple bidding mechanisms, credit, negative prices, the opportunity to delegate bidding, a fairness committee, the ability to bid jointly and mix lots, the daily reallocation of shares, the use of a fully
functioning demonstration game, and so on - that made the difference. That some of these buttresses were not ultimately necessary may hardly be the point, as much of the implementation of this system was political.

The apparent success of the Choice System raises other possibilities. First, could it be extended to other parts of the food distribution chain? For example, the Chicago Food Depository distributes food to many parts of the city, some of which are blighted with greater poverty than others. Would it be possible to set up a system of fake currency to do better than charging food pantries real money? As one possibility, could they give credit cards denominated in fake currency with which to distribute food from its warehouses? While this has its challenges - not least the fact that many clients of food banks commute from where they live to a food bank in another neighborhood - the outcomes of the Choice System may open some possibilities. Second, one of the desires of this system was to equalize inequalities caused by food richness. Yet it appears that the food rich are largely sorting into the most expensive goods as they already have an adequate supply of the staples. If so, how about taxing the most expensive goods in the sense that some of the proceeds from these sales are not distributed to everyone, but only to those foods banks whose average purchasing is of lower priced goods? While the Choice System has likely helped the food poor by allowing them to concentrate best on the lower priced good, perhaps more direct redistribution could be beneficial.

Second, one objective of the system is to rebalance the field in favor of the food poor. This has arisen not through any explicit system of redistribution - other than the 10% tax on maroon pounds - but rather by the sorting of the market. However, one thing that seems clear is that the food rich are sorting into the most expensive products. This raises the possibility of a luxury tax on high priced goods, where the revenues of high quality goods would be redistributed not to all food banks based on goal factors, but disproportionately redistributed to those food banks who buy low priced goods.

A third issue may become worth of further exploration, which is the issue of nutrition. The use of bidding has also likely facilitated a new form of sorting that has occurred over the last decade. A new trend among some food banks is to be less focused on volume of food for the poor, but instead nutrition has become the focus of many food banks. (It is of course ridiculous to claim that any food bank is not concerned with nutrition: instead, a recent trend is for some food banks to focus much more intensively on this issue.) For these food banks, their bidding is now more focused on a set of foods which Feeding America has labeled “Foods to encourage”, those with the highest nutritional value. Yet this trend is far from universal, and for many food banks their priority remains the alleviation of hunger through a wide variety of foods. This divergence in preferences would have been very difficult to administer under a centralized assignment system. The Choice System allows this divergence to be naturally reflected in different offerings to the poor across geographic areas.
Despite the apparent success of this allocation system - with more food being better allocated across the country - the Task Force was far from omniscient. The most substantive problem remains produce, which traded on the Choice System exactly like any other good. Produce is problematic as it spoils quickly.\textsuperscript{32} As a result, it is a relatively low value food to food banks, especially as transportation costs can be large. The Choice System does take time; at least a day to sell, and then it needs to be transported to a food bank, and from there to a pantry or soup kitchen. As I write, a decision has been made at Feeding America to take produce from the Choice System, and reallocate it to a new platform that will allow it to move more quickly, where the food is simply given to the food bank that can collect it fastest. Perhaps it would have been valuable to adapt the Choice System for goods that need to transact rapidly. As such, the Choice System has not been a panacea for all ills. Despite this, we believe that its architecture has lead to some robust successes that may be valuable for other possible applications in the not-for-profit sector.

\textsuperscript{32}Produce is also a problem as it is not clear how much is actually used by end users. Sometimes this is because they do not know well how to cook certain kinds of food. This part of the reason that some food pantries have moved towards prepared meals over the last decade.
REFERENCES


**Task Force Members (and their affiliations at the time):**

John Alford, Chair, Mississippi Food Network, Jackson, MS
John Arnold, Second Harvest Gleaners FB, Grand Rapids, MI
Al Brislain, A2H Senior Vice President, Affiliate Services
Bill Clark, Philabundance, Philadelphia, PA
Phil Fraser, SHFB of Santa Clara/San Mateo, San Jose, CA
Maria Hough, A2H Managing Director of Logistics
Mike Halligan, A2H Senior Vice President, Business Development & Logistics
Brenda Kirk, Houston Food Bank, Houston, TX
Rob Johnson, Atlanta Community Food Bank, Atlanta GA
Susannah Morgan, Food Bank of Alaska, Anchorage, AK
Steve Sellent, Great Plains Food Bank, Fargo, ND
Roger Simon, The Idaho Foodbank, Boise, ID

**Advisors:**

Harry Davis, Professor, University of Chicago
Don Eisenstein, Professor, University of Chicago
Robert Hamada, Professor, University of Chicago
Canice Prendergast, Professor, University of Chicago
Changes to the Goal Factor  
Under the old system, this was a weighted average
of population and poverty of an area relative to the national average for food bank \( i \) via

\[
[(\text{Population}_{i}/\text{USPopulation}) + (\text{PovertyPopulation}_{i}/\text{USPovertyPopulation})].
\]

(23)

This was changed to one which applied empirical weights based on usage, as many over
the national poverty level use food pantries and soup kitchens. The new definition
has three components: those under the poverty line, those between the poverty line
and 185% of the poverty line, and those above 185% of the poverty lone, using usage
weights for the three groups. The formula is now given by

\[
0.73(\text{Pop < 100\%Poverty})_{i} + 0.22(\text{Pop[> 100\%but < 185\%]}_{i}) + 0.05(\text{Pop > 185\%})_{i} \\
0.73(\text{U.S.Pop < 100\%}) + 0.22(\text{U.S.Pop[> 100\%but < 185\%]}) + 0.05(\text{U.S.Pop > 185\%})
\]

(24)
Table 1: Average Price paid by a Food Bank (2008)

<table>
<thead>
<tr>
<th>Variable</th>
<th>$\beta$ (t-statistic)</th>
<th>$\beta$ (t-statistic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.241** (6.91)</td>
<td>0.21** (6.42)</td>
</tr>
<tr>
<td>Goal Factor</td>
<td>0.214** (5.04)</td>
<td>0.203** (5.34)</td>
</tr>
<tr>
<td>Blue Pounds/GF</td>
<td>-</td>
<td>2.166** (2.77)</td>
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</table>

Table 2: Log Pounds for a Food Bank (2008)

<table>
<thead>
<tr>
<th>Variable</th>
<th>2008: $\beta$ (t-statistic)</th>
<th>2004: $\beta$ (t-statistic)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>5.724** (64.64)</td>
<td>4.21** (56.42)</td>
</tr>
<tr>
<td>Goal Factor</td>
<td>0.158 (1.24)</td>
<td>0.451** (4.45)</td>
</tr>
</tbody>
</table>
Appendix

The Competitive Equilibrium: We use the revelation principal to induce the competitive equilibrium. Let a food bank of type $D$ make a report $\hat{D}$ to the principal, where the equilibrium utility of the agent is $U(D; \hat{D})$. Then the objective of the principal in a given interval is to

$$\max_{q_A(D), q_B(D)} \sum_d U(D; D)$$

subject to $U(D; D) \geq U(D, \tilde{D})$ for all $\tilde{D}$, $q_i(D) \geq 0$ for all $i$, $q_A(\bar{d}) + q_A(\bar{d}) \leq Q$, and $q_B(\bar{d}) + q_B(\bar{d}) \leq \mu Q$.

Proof of Lemma 1: First, it must not violate the non-negativity constraint, here manifested by $q_A \geq 0$. This requires that $q_A \geq 0$, or

$$\frac{2Q}{n} \geq (\delta - 1)d.$$

The outcome of this competitive equilibrium is that the food poor receive more than their share of good $A$ and that the food rich receive more of good $B$. But this means that the food rich must be “bribed” by getting more of good $B$. Consider the food rich $\bar{d}$. The allocation above is only feasible if type $\bar{d}$ is satisfied with his allocation. This requires that

$$\bar{q}_B - q_B \geq \tau(q_A - \bar{q}_A) - \gamma \left( \frac{(\bar{d} + q_A)^2}{2} - \frac{(\bar{d} + q_A)^2}{2} \right).$$

As $q_B \geq 0$, this implies a lower bound on the supply of good $B$.

Additionally, the allocation is only feasible if type $\bar{d}$ is satisfied with his allocation, as he could mimic the $\bar{d}$ type. This requires that

$$q_B - \bar{q}_B \geq \tau(\bar{q}_A - q_A) - \gamma \left( \frac{(d + q_A)^2}{2} - \frac{(d + q_A)^2}{2} \right).$$

This implies a lower bound on $q_B$ (or equivalently an upper bound on how much $B$ goes to the food rich) for this outcome to be feasible.

First consider the food rich, type $\bar{d}$ given (6) and (5). The allocation above is only feasible if type $\bar{d}$ is satisfied with his allocation. This requires that

$$\bar{q}_B - q_B \geq \tau(\delta - 1)d + \frac{\gamma}{2} \left( \frac{x_A^2}{4} - \frac{(3\delta - 1)d^2}{4} \right).$$
Equally, this allocation is only feasible if type \(d\) is satisfied with his allocation, as he could mimic the \(\bar{d}\) type. This requires that
\[
q_B - q_B \geq -\tau(d - 1)d + \frac{\gamma}{2} \left( \frac{x_A^2}{4} - \frac{((\delta + 1)d^2)}{4} \right). \tag{30}
\]
Subtracting (30) from (29) implies both can be simultaneously satisfied if
\[
q_B - q_B \geq 2\tau(d - 1)d - \frac{\gamma}{2} \left( \frac{(\delta + 1)d^2}{4} - \frac{(3\delta - 1)d^2}{4} \right). \tag{31}
\]
But \(q_B - q_B\) cannot exceed \(\frac{\mu Q}{n}\), which implies that \(\mu\) must weakly exceed \(\mu^*\) to be feasible.

**Corner Solutions** The corner solution involves either the food poor receiving all of good \(A\), the food rich receiving all of good \(B\), or both. The first case where a corner arises is if there is enough of good \(A\) to equate marginal utilities on that good \(\left(\frac{2Q}{n} \geq (\delta - 1)d\right)\) but \(\mu < \mu^*\). In that case there is not enough good \(B\) to offer to type \(\bar{d}\) and so the allocation must assign some \(q_A\) to the food rich type, thereby no longer equating marginal rates of substitution. The allocation is then given by \(q_B(\bar{d}) = \mu Q, q_B(d) = 0\) and \(\bar{q}_A\) is given by
\[
\frac{\mu Q}{2n} = \tau(\frac{Q}{n} - 2\bar{q}_A) - \gamma \left( \frac{(\bar{d} + \bar{q}_A)^2}{2} - \frac{(\bar{d} + \frac{Q}{n} - \bar{q}_A)^2}{2} \right). \tag{32}
\]
Solving this for \(\bar{q}_A\) yields
\[
\bar{q}_A = \frac{(\mu - \tau)Q - \frac{\gamma}{2}(2\delta dQ + Q^2)}{2\tau - \frac{\gamma}{2}(4\delta d + 2Q)}. \tag{33}
\]
This is also the outcome if there is not enough \(Q\) to equate marginal rates of substitution on \(A\) but the food rich wishes to deviate.

The other corner solution arises when there is not enough of the staple good to equate marginal rates of substitution: \(\frac{2Q}{n} < (\delta - 1)d\). Here the food poor receive all of good \(A\) and enough of good \(B\) to satisfy their incentive to deviate. If the food poor’s incentives are violated at \(q_A = Q\), then the principal chooses \(q_B\) sufficiently high such that
\[
q_B - q_B \geq -\tau \frac{Q}{2n} + \gamma \left( \frac{(d + \frac{Q}{2n})^2}{2} - \frac{d^2}{2} \right). \tag{34}
\]
The final corner that arises is where \(\frac{2Q}{n} < (\delta - 1)d\) but neither party’s incentive constraint is violated at the constrained efficient outcome where all of good \(A\) goes to the food poor and all of good \(B\) goes to the food rich. In this case, \(q_A = \frac{Q}{2n}\) and \(\bar{q}_A = \frac{\mu Q}{2n}\). This case arises for \(\mu \in \{\tau - \gamma(d + \frac{Q}{2n}), \tau - \gamma\delta d\}\). This completes the description of the competitive equilibrium.
Competitive Equilibrium with Equal Incomes and Symmetric Redistribution: First consider the case where by assumption all parties spend a total amount of 1 during any interval $I$. Further assume that their objective function is to choose a $q_i$ rather than bid $b_i$: this will be relaxed below. Then the objective of each party is to

$$\max_{q_A, q_B} \tau(D + q_A(D)) - \gamma \left( \frac{D + q_A(D)}{2} \right)^2 + q_B(D) + \mu D.$$  \hspace{1cm} (35)

First consider the case where the first order conditions hold. Note that with budget balance (where expenditure is 1 in an interval), $\frac{dq_B}{dq_A} = \frac{p_A}{p_B}$. As a result, the first order condition for the food bank of type $D$ is given by

$$\frac{p_A}{p_B} = \tau - \gamma(d + q_A(D)).$$  \hspace{1cm} (36)

Then consider an equilibrium where

$$\frac{p_A}{p_B} = \tau - \gamma \left( \frac{Q + \frac{\delta+1}{2}d}{n} \right).$$  \hspace{1cm} (37)

Then by substitution,

$$\overline{q}_A = \frac{Q}{n} - \left( \frac{\delta - 1}{2} \right)d,$$  \hspace{1cm} (38)

and

$$\underline{q}_A = \frac{Q}{n} + \left( \frac{\delta - 1}{2} \right)d,$$  \hspace{1cm} (39)

as required for competitive equilibrium. If the budget is balanced with total expenditures of 1, then

$$q_B(\overline{d}) = \frac{\mu Q}{n} + \left( \frac{\delta - 1}{2} \right)d \frac{p_A}{p_B},$$  \hspace{1cm} (40)

and

$$q_B(\underline{d}) = \frac{\mu Q}{n} - \left( \frac{\delta - 1}{2} \right)d \frac{p_A}{p_B}.$$  \hspace{1cm} (41)

These quantities are only feasible if they satisfy budget balance, which requires

$$p_A \overline{q}_A + p_B \overline{q}_B = 1,$$  \hspace{1cm} (42)

and

$$p_A \underline{q}_A + p_B \underline{q}_B = 1,$$  \hspace{1cm} (43)

subject to $\overline{q}_A + q_A = Q$, and $\overline{q}_B + q_B = \mu Q$, and the equilibrium quantities above. Substituting for relative prices from (22) yields absolute prices as

$$p^*_A = \frac{1 - \frac{\mu Q - \mu d(\delta - 1)}{\mu Q + \mu d(\delta - 1)}}{\Omega}.$$  \hspace{1cm} (44)
where $\kappa$ is the relative price level as above, and
\[
\Omega = \left( \frac{Q + (\delta - 1)d}{2} - \left( \frac{\mu Q - \kappa d(\delta - 1)}{\mu Q + \kappa d(\delta - 1)} \right) \left( \frac{Q - (\delta - 1)d}{2} \right) \right)
\]
and
\[
p_B^* = \kappa p_A. \tag{45}
\]

Now consider relaxing the two assumptions above. First, now let food banks bid $b_i(t)$ for good $i$ in period $t$, where their bids can depend on the amount of each good that they have previously won. If all parties, bid a constant amount $b_i(t) = p_i^*$ if $\sum q_i(t) \leq q_i^*$ (where $q_i^*$ is the equilibrium quantity above) and $b_i(t) = p_i^*$ if $\sum q_i(t) = q_i^*$, then all parties - by the assumption of enough divisibility - receive exactly $q_i^*$ at period $T$. But if all parties receive $q_i^*$ at period $T$, no food bank has an incentive to change its bid from the bidding function above and all parties have spent a total amount of 1 when period $T$ ends.

The final piece is to note that there is not reason to inter-temporally substitute across intervals. All intervals are independent and identical, and the shadow price of a unit of currency in any future interval in this equilibrium is the equilibrium marginal utility of a unit of good $A$ which is $\frac{x_i^*(Q)}{p_A} = \frac{\delta + \frac{1}{2}}{p_A}$, and so there is no value to moving expenditures across intervals. Hence this is a competitive equilibrium of the repeated interval game.

As mentioned in the text, this requires that there is availability of both goods to satisfy equating marginal rates of substitution and to avoid mimicking by each type. From (31), this requires that $\mu \geq \mu^*$. Now consider the case where this is not satisfied. The competitive equilibrium is described in the proof of Lemma 1. To compute the prices that implement this, note that
\[
p_A q_A + p_B \mu Q = 1, \tag{46}
\]
and
\[
p_A q_A = 1, \tag{47}
\]
which uniquely defines
\[
p_A = p_A = \frac{\mu Q}{Q - 2q_A}, \tag{48}
\]
where the absolute price levels are given by (46) and (47) and $p_B = \frac{Q - 2q_A}{\mu Q q_A}$. It is simple to show that at those relative prices, the food poor spend all their income on $A$ and the food rich are willing to purchase all of $q_B$. A similar proof holds for the case where $Q$ is too low to equate marginal rates of substitution.

The second corner solution is where $\frac{2Q}{\tau} < (\delta - 1)d$. In this case, the marginal valuation of all units of $A$ are valued more highly by type $d$. As a result, ignoring the incentive compatibility constraints, all of $A$ should go to type $d$. The only case where it will not is if there is not enough good $B$ to satisfy the $d$ type in which case an identical analysis to the above case follows. This leaves two remaining cases. The first is where neither incentive compatiblity constraint is violated with complete segregation, where $q_B = \mu Q$ and $q_A = Q$. This arises if $\mu \in \{\tau - \gamma(d + \frac{Q}{2\gamma}); \tau - \gamma \delta d\}$. 46
In this case, prices that implement the competitive equilibrium are trivial, and given by $p_B = \frac{1}{\mu Q}$, and $p_A = \frac{1}{Q}$.

However, this equilibrium is not feasible if $\mu$ is large, as the food poor type would prefer to get the share of the food rich. As a result, in this case $q_B < \mu Q$, $q_B > 0$ and $q_A = Q$. In this case, the principal chooses $q_B$ to satisfy (34), and where prices that implement this are given by

$$p_A Q + p_B q_B = 1,$$

and

$$p_B = \frac{1}{q_B},$$

which uniquely defines

$$\frac{p_A}{p_B} = \frac{\mu Q - 2q_A}{Q}.$$  

(51)

This completes the description of the delegation of competitive equilibrium through bidding with equal incomes.

**Welfare with Corner Solutions:** To follow.

**Composition of Food:** First note that relative prices remain at $\kappa$, as the noise washes out in equilibrium with large $n$. Given those prices, the quantity of good $A$ purchased by food bank $i$ of type $D$ is now simply given by $q_{Ai} = \frac{Q}{n} - \lambda_i - \frac{(\delta - 1)d}{2}$ and $q_{Ai} = \frac{Q}{n} - \lambda_i + \frac{(\delta - 1)d}{2}$. While these transitory shocks do not affect total quantities $x^*$ consumed under the Choice System, they do affect the welfare from the old system.

Welfare under the old assignment rule is now given by

$$\hat{U} = (\tau + \mu)(\bar{d} - \frac{d}{2})\frac{Q'}{n} - \frac{\gamma}{8} \left( \bar{d}^2 + \frac{Q'}{n} \right)^2 + (\bar{d} + z + \frac{Q'}{n})^2 + (\bar{d} - z + \frac{Q'}{n})^2 + (\bar{d} - z + \frac{Q'}{n})^2 \right)$$

(52)

The value of the choice system over the market then becomes

$$\Delta \hat{U} = U^* - \hat{U} = \Delta U + \frac{\gamma}{8} z^2,$$

(53)

so that the choice system offers an additional benefit through smoothing compositional shocks to supply. It remains the case that these are reflected in the variance of average quantities by food bank.
Welfare Gains from Credit: Differences across food banks don’t always imply permanent differences. In many instances, a food bank may have an unexpected shortfall in supply of food elsewhere, or it may have a shock to demand, such as when a local employer closes. Assume now that a food bank has a shock to its supply of good $A$ given by $\epsilon$ where the distribution of $\epsilon$ is given by $G(\epsilon)$ with mean 0 over a support with a lower bound of $\epsilon$. Assume that the number of food banks is large enough that there is no meaningful variation in aggregate supply.

If food banks cannot borrow or save, the distinction between a transitory or a permanent shock is irrelevant as all shocks are isolated to a single interval. Consider a case where food banks do not use saving as a mechanism for smoothing across intervals, but instead use credit. Credit works in a limited way here, as loans are quite short run, with a debt typically paid back in the following month. Given this, consider the role of short term credit - at zero interest - where a loan that is taken out in one interval is paid back in full in the next interval.

As a concrete example, consider a food bank with endowment $d + \epsilon_1$ in interval 1. It can borrow against interval 2 to increase its current consumption. Note that the food bank never borrows to buy good $B$ as the marginal utility of consumption is constant in each period, instead it borrows to buy good $A$. It is simplest to work in quantity space, so let us assume that the food bank borrows to consume an extra $\Delta q_A$ in this interval, to be paid back in interval 1. First note that the agent will only seek credit if he cannot afford to spend all his endowment to reach his average allocation given by $\frac{p_A}{p_B} = t - \gamma(q_A^* + d)$, which implies that credit may only be used if $\epsilon < \bar{\epsilon}$, where $\bar{\epsilon} = \frac{1}{p_A} - q_A^*$.

The downside to seeking credit is that next interval’s shock could be worse, so credit markets are not free here. Let $\hat{\epsilon}$ be the shock next interval where the credit constraint binds. Then the equilibrium choice of the agent is that $\Delta q$ satisfies

$$t - \gamma(q_A^* + d + \epsilon + \Delta q_A(\epsilon)) = [1 - G(\hat{\epsilon})]\frac{p_B}{p_A} + \int_{\epsilon}^{\hat{\epsilon}} t - \gamma(q_A^* + d + x - \Delta q_A(\epsilon))dG(x). \quad (54)$$

This simplifies to

$$\Delta q_A(\epsilon)(1 + G(\hat{\epsilon})) = \frac{1 - G(\hat{\epsilon})}{\gamma} \left[ \frac{p_A}{p_B} - (t - \gamma(q_A^* + d)) \right] + \epsilon - \int_{\epsilon}^{\hat{\epsilon}} x dG(x) \quad (55)$$

After substituting for equilibrium prices, this becomes

$$\Delta q_A(\epsilon)(1 + G(\hat{\epsilon})) = \frac{1 - G(\hat{\epsilon})}{\gamma} \lambda + \epsilon - \int_{\epsilon}^{\hat{\epsilon}} x dG(x), \quad (56)$$

where $\lambda = \int_{\epsilon}^{\hat{\epsilon}} x - \frac{1 - G(\hat{\epsilon})}{\gamma} \Delta q_A(\epsilon) dG(x) dF(d)$. This is credit conditional on choosing to use credit, so ultimate credit received is $q_{AC} = max\{0, \Delta q_A\}$. 

48
In simpler terms, this formula gives the partial insurance achieved by food banks from the availability of credit. As above, this translates into a welfare gain proportional to $\gamma E(\Delta q_{AC}^2)$ so we can measure welfare gains from the use of credit via its level.

**Transitory Errors in Estimating Prices:** Consider a case where in each time period $t$, food bank $i$ believes with probability $\rho$ that the price of good $i$ is a $(1 - f)p_i$, and with probability $\rho$ that the price of good $i$ is a $(1 + f)p_i$. It believes these to be permanent. With probability $1 - 2\rho$, its beliefs are correct. The draw is receives on this is independent across time periods. (This may seem an odd assumption in this two good setting, but realistically, a food bank might see one kind of cereal on one day and a different kind of cereal the next day, and can make errors on each which need not be the same.) $n$ is large enough that the population distribution occurs each period. In each case, the food banks follow the same strategy as above in that they bid their belief about the price if their quantity is below their preferred level and below that otherwise.

The timing of the revised model of an interval is as follows. At date 0, before any types are known, equilibrium prices are computed. This computation is done knowing that agents will hold mistaken beliefs in the future. Types are then revealed for $t = 0$, agents make a bid of their belief of prices. If the price bid falls below the market clearing price, the food bank receives no food. If the price bid by a food bank is above the market clearing price, that food bank gets the same allocation as those food banks that bid the market price. Date 1 then begins with new types being revealed, and so on, until the end of the interval.

Equilibrium relative prices remain unchanged at $\kappa$, as all parties hold the same beliefs about relative valuations as above. There are two possible distortions here. First, the food bank that bids below the equilibrium prices receives no food. Second, the food bank that bids too much runs down its budget too fast and is in danger of not being able to afford its equilibrium allocation. The latter is not relevant for efficiency. The reason is that as prices are computed at date 0, the absolute price levels adjust to clear the market.

But clearing the market does not imply that all food banks receive their optimal ex ante levels. The reason has to do with the distribution of positive and negative signals. A distortion arises if some food banks receive more positive $f$ draws to price beliefs and some receive too little. The equilibrium distortion is that a food bank believes prices are too low, and does not get enough food, leaving the residual to those who have either neutral or positive draws.

What matters for distortions is then the distribution of positive and negative draws: as the dispersion of this distribution converges to 0, distortions disappear despite errors made by the agents. This distribution is Binomial where the probability
of receiving $z$ more negative draws than positive draws in any interval is given by

$$H(z) = \frac{T!}{z!(T - z)!}\rho^z \rho^{T-z}. \quad (57)$$

As $T$ gets large or as $\rho$ gets small, this distribution collapses around $\frac{z}{T} = 0$ and so the distortion disappears.
Figure 1: Website
Figure 2: Price per pound
Figure 3: The Distribution of Food
Figure 4: Prices of Different Foods
Average Pounds per Share spent by Food Bank: 2008

Figure 5: The Distribution of Average Prices Paid by Food bank
Figure 6: % of Trades that Involve Credit
Figure 7: % of Trades with Negative Prices
% Loads Selling for Non-positive Prices: 2005-2011

Figure 8: % of Trades with Non-Positive Prices
Figure 9: Yellow Pounds in the Choice System
<table>
<thead>
<tr>
<th>Year</th>
<th>Total Pounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>143,684,016</td>
</tr>
<tr>
<td>2006</td>
<td>328,419,345</td>
</tr>
<tr>
<td>2007</td>
<td>348,098,864</td>
</tr>
<tr>
<td>2008</td>
<td>359,043,166</td>
</tr>
<tr>
<td>2009</td>
<td>350,446,167</td>
</tr>
<tr>
<td>2010</td>
<td>336,135,436</td>
</tr>
<tr>
<td>2011</td>
<td>337,081,335</td>
</tr>
</tbody>
</table>

Figure 10: Total Pounds in the System
Maroon Pounds (millions): 2005-2012

Figure 11: Maroon Pounds
The Average Price of a Pound of Food: 2005-2011

Figure 12: Average Price Over Time