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Inferring shortfall costs and integrating environmental costs into optimal production levels for an all-you-care-to-eat food service operation

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ABSTRACT

This study examines how optimal food production policies at an all-you-care-to-eat (AYCTE) facility would change were life cycle cost estimates of embodied CO2 included in the disposal costs associated with overproduction, in an aim to study production planning possibilities in a situation that places increased emphasis on the environmental impacts of overproduction. AYCTE operations exhibit a lack of revenue associated with each item served, since there is no per-item lost sales value incurred when demand exceeds supply; accordingly, the second objective of this research is to present a novel method for estimating shortfall costs in a setting with no marginal revenue per satisfied unit of demand. We examine empirical data from AYCTE operations at the University of Missouri's Campus Dining Services (CDS) to infer the per-item shortfall costs that are implied by CDS management's historical production decisions. Consistent with CDS management's stated aversion to shortfalls, we estimate shortfall values which are between 1.6 and 2.7 times larger than the procurement cost and between 30 and over 100 times larger than the disposal cost. Utilizing published estimates of life cycle CO2 and the social cost of carbon, we identify a per-portion environmental cost. We incorporate the environmental costs associated with wasted overproduction and the inferred shortfall cost estimates into a newsvendor model formulation, to identify new optimal production levels, illustrating this approach with application to a set of food items served by CDS. We find that optimal production levels are decreased significantly (18–25%) for food items with high environmental impacts (such as beef), and reduced less for foods with less embodied CO2.

1. Introduction

In recent years, a number of studies have led to increasing societal awareness of the environmental effects of food waste (Kantor et al., 1997; Griffin et al., 2008; Buzby and Hyman, 2012; FAO, 2013). The United Nations Food and Agriculture Organization (FAO, 2013) study, for example, estimated that one-third of all food produced for human consumption in the world is lost or wasted. While there is no consistently-applied definition of the term *food waste*, the framework developed by the FAO (2013) provides a supply-chain perspective divided into six phases: agricultural production, post-harvest handling and storage, processing, distribution, consumption, and end of life. Although waste occurs at all phases of the food supply chain, the largest losses in developed nations occur at the consumption stage; e.g., 54% of waste is estimated to occur at the consumption stage for North America and Oceania (FAO, 2013).

Accordingly, food waste at the consumption phase has been more thoroughly investigated than waste at other phases (Engström and Carlsson-Kanyama, 2004; Parfitt et al., 2010). Due to difficulties associated with collecting data from individual households, most studies have further focused on food waste in institutions such as schools (Buzby and Guthrie, 2002), colleges (Al-Domi et al., 2011, Costello et al., 2016) and hospitals (Williams and Walton, 2011).

Food waste at the consumption stage can be further categorized as either *pre-consumer* or *post-consumer* waste. Pre-consumer waste is generated from such sources as storage loss, preparation

Abbreviations: AYCTE, all-you-care-to-eat; CDS, Campus Dining Services; CDF, cumulative density function; CO2, carbon dioxide; CVaR, conditional value-at-risk; EPA, United States Environmental Protection Agency; FAO, United Nations Food and Agriculture Organization; g, grams; GHG, greenhouse gases; PDF, probability density function; SCC, social cost of carbon

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loss, and serving loss, whereas plate waste and overproduction comprise post-consumer waste. The current literature on food waste reduction approaches has primarily focused on strategies for minimizing plate waste that is served to consumers but not eaten (Williams and Walton, 2011; Al-Domi et al., 2011).

In this study, we investigate the environmental impact of overproduction food waste (i.e., discarded leftovers, which are an element of post-consumer waste), in an aim to study production planning possibilities in a situation that places increased emphasis on the environmental impacts of overproduction, contributing to the literature on optimal food service production planning by incorporating the impact of environmental considerations. In particular, we examine the influence of overproduction on the optimal production level for food items served at the University of Missouri Campus Dining Services (CDS). This setting is of particular interest because CDS operates all-you-care-to-eat facilities (AYCTE), for which there is no value for lost revenue that can be utilized as an estimate of shortfall (inventory stockout) costs. Given the absence of existing literature detailing how one might compute shortfall costs in such an environment, the second significant contribution of this research is to present a novel method for estimating shortfall costs in an AYCTE setting, inferring the value that current management places on shortfalls as a consequence of its historical production decisions. We limit our attention to single-period food products (i.e., overproduction cannot be stored and later served as leftovers, but must be discarded). These items are produced from frozen inventories, and can effectively be thought of as having no storage loss prior to production. Because these are single period items, there is no holding cost value; rather, a disposal cost is incurred for each overproduced item. The most straightforward interpretation of disposal cost is simply the landfill cost incurred when this item enters the solid waste stream. However, recognizing that wasted food also wastes upstream resources associated with food production, we extend disposal costs to include estimates of the carbon dioxide (CO2) emissions embodied in wasted food, to identify the extent to which inclusion of these environmental costs impacts optimal production levels.

The remainder of this paper is organized as follows. Section 2 contains a review of the related literature. Section 3 presents our approach for estimating the shortfall costs implied by historical production decisions, demonstrating our analytic approach using empirical data from a set of food items commonly produced by CDS. Section 4 presents an analysis of the impact of including environmental costs on optimal production levels, utilizing the same set of CDS food items to illustrate our approach. Section 5 then presents conclusions and suggestions for further research.

2. Literature review

Consistent with the two main objectives of this research, this literature review first focuses on the existing literature for estimating shortfall costs, in particular approaches that estimate these costs based on empirical data. The second part of this section focuses on approaches for estimating the environmental costs associated with food waste (or, in operations research parlance, overproduction).

Food service operators face a variant of the standard production planning problem. For some food items, when overproduction occurs, relative to demand, the excess production cannot be retained for future use. Common examples of such food items are fried foods, such as french fries or fried chicken patties. Since such food items constitute a single-period production system, optimal production policies can be identified using a variant of the newsvendor model (Hadley and Whitin, 1963). The aim of the newsvendor problem is to define an optimal inventory level in the event of uncertain demand, balancing the effects of holding costs (when production exceeds demand) with those of shortfall costs (when demand exceeds production).

A number of studies have considered optimal production decisions in a food service environment. Ryu and Sanchez (2003) developed demand forecasting approaches to address overproduction and shortfall at institutional food service operations. Goto et al. (2004) used Markov decision processes to identify minimum cost strategies for airline flight catering, investigating the tradeoff between having overage and shortage meals on a flight. Rivera and Azapagic (2015) contrasted the life cycle costs and environmental impact of the production and consumption of ready-made meals, when contrasted with similar meals prepared at the consumer's home. Extending the scope beyond food service operations, many studies have examined the related field of perishable inventory. Nahmias (1982) provides a review of the early literature in this area, much of which is related to food items. Non-food related applications are also numerous, such as Eppen and Iyer (1997), which examines ordering decisions for fashion inventory.

There are four costs associated with inventory in a newsvendor model: (1) ordering cost (2) setup cost (3) holding cost and (4) shortage cost (Malakooti, 2013). In the context of our food production problem, we view the ordering cost as the cost necessary to produce a food item, including the procurement of the necessary ingredients, and the setup cost as negligible. Since it is assumed that all overproduction of such food items goes directly into the solid waste stream, we do not have a holding cost per se. However, since there is a disposal cost associated with these overproduced items, we will initially consider this disposal cost as defining our holding cost in the model.

2.1. Shortfall costs

A particular characteristic of AYCTE food service operations that complicates the identification of optimal production policies is the lack of revenue associated with each individual item served. In this context, there is no per-item lost sales value that is incurred when demand for a particular food item exceeds the available supply. Thus, in this study, shortfall cost represents only “loss of goodwill”. In interviews, CDS management stated a strong aversion to shortfalls at their AYCTE facilities, although they were not able to provide an estimate of the cost value placed on shortfalls. Therefore, we will utilize a newsvendor model to infer a range of shortfall costs implied by CDS' current production practices, using these estimates to reflect their implied (but unstated) valuation of shortfalls.

Although shortfall costs are one of the most important parameters necessary to utilize a newsvendor model of production, there has been limited research published on approaches to estimating a shortfall cost when there is no direct link to lost revenue. Ishii and Konno (1998) considered a newsvendor model in which the shortfall cost was assumed to be given by a fuzzy number. Wu et al. (2013) considered a model with uncertainty in demand along with uncertainty in shortage cost using a Conditional Value-at-Risk (CVaR) approach. However, neither of these studies addresses how one might estimate a baseline shortfall cost from an actual production environment.

Moreover, classical references for inventory management (Axsäter, 2015; Teunter et al., 2009; Zipkin, 2000) do not contain any discussion for how one might obtain a shortfall cost; rather, these authors provide approaches for utilizing a given shortfall cost. This is problematic, since, as noted by Axsäter (p.45):

Because shortage costs are so difficult to estimate, it is very