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A Newsvendor Approach to Compliance and Production under Cap and Trade Emissions Regulation

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1. INTRODUCTION

Climate change is a growing concern among scientists, businesses, and the public at large (Pan, Ballot, & Fontane, 2013). The consensus of scientists is that the use of fossil fuels has a direct and detrimental effect on the environment. The Intergovernmental Panel on Climate Change (IPCC) reports that it is extremely likely that human activities, such as those that result in fossil

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fuel emissions, are increasing concentrations of carbon in the atmosphere, contributing to global warming (IPCC, 2013). Since the 1990s, governmental agencies have increasingly turned to market based cap and trade programs to control the emission of pollutants. Cap and trade programs have gained favor with both governing bodies and regulated organizations because such programs enable parties to choose among a variety of mechanisms to achieve regulatory compliance (Majumdar & Marcus 2001). These mechanisms include the reduction of emissions through operational improvements as well as the attainment of compliance through the open market acquisition of emissions allowances. While emissions reduction efforts may eliminate the need for some firms to acquire additional allowances, other firms will have emissions levels that require the purchase additional allowances on the open market. This study presents a new forward buying heuristic, designed for those firms that need to purchase emissions allowances via auctions, which reduces the impact of emissions allowance acquisitions on the firms' financial performance. This matter is of great importance to firms subject to cap and trade regulation, because they are faced with the operational challenge of developing cost effective environmental strategies in business environments where it often is difficult to pass compliance costs onto customers (Schofield, 2013).

In cap and trade programs, a total emissions volume cap is set by a regulatory authority, which then issues a number of allowances (often in the form of certificates) corresponding to that total emissions volume cap (in most programs, one allowance authorizes the emission of one ton of a targeted pollutant) (Chaabane, Ramudhin, & Paquet, 2012). Regulated firms then are required to obtain allowances equivalent to the volume of a pollutant they emit through operational activities or else pay a severe penalty. A primary motivation of cap and trade programs is that the costs to acquire allowances are substantial enough that firms choose to avoid the compliance costs and instead invest in efforts to permanently eliminate emissions. However, in many industries, zero emissions operations may be unattainable; in which case firms will need to acquire allowances for any remaining emissions. Allowances are acquired in several ways: they are allocated by the regulatory authority to firms free of charge (a process known as grandfathering), purchased via auction, or traded between firms on the open market. Allowances typically can be "banked" by a firm and held for use in future periods (EPA, 2002). Allowances are also highly fungible; therefore firms can easily sell excess certificates on the open market, which can contribute directly to profitability (Zhang & Xu, 2013).

The task of developing cost-effective production and allowance procurement programs is complicated by dramatic fluctuations in the market prices of emissions allowances. For example, since the inception of the European Union's Emissions Trading System (EU ETS), which is one of the most recognized emissions reduction programs, the auction price for CO_2 has ranged from a high of more than €30.00 per allowance to a low of €0.01 per allowance. In situations such as these, price fluctuations (combined with the limited ability to pass the costs onto consumers) create a problem in which firm profits can fluctuate even when the selling price of the finished product, material and labor inputs, and customer demand are stable.

For firms that need to acquire additional allowances via auction, this study presents a flexible heuristic that can be used by firms operating under any existing or future market based cap and trade regulatory program. The intention of the study is not to develop or challenge the regulatory policies of the various cap and trade programs but rather the study presents a tool for firms to use when the existence of an auction based allowance market is an externality with conditions beyond the influence of individual firms. Specifically, this paper examines the feasibility of applying an extended version of a Newsvendor heuristic to the emissions allowance procurement and production problem. This approach is motivated by the similarity between scenarios in which firms are impacted by market price fluctuations of emissions allowances and scenarios in which manufacturing firms are required to procure commodity raw materials through spot markets. In the extant Operations Management literature, two primary approaches have been developed to address the commodity procurement problem. In one approach, multiperiod order quantities are secured at favorable market prices via contracts (Sethi, Yan, & Zhang, 2004). In the other approach, forward buying heuristics procure materials for future periods' demand when the purchase price differential (current versus future) will outweigh the costs of holding the material as inventory (Golabi, 1985). Both of these approaches have been shown to reduce acquisition costs by taking advantage of drops in spot market prices; however, the forward buying approach is more appropriate for the emissions allowance procurement problem. This is because the contractual approach often requires third parties to act as allowance brokers; a practice which is not permitted under some cap and trade programs (such as the EU ETS) which mandate that firms purchasing allowances must have the intention of actually using them for their own operations (European Union, 2010). Recently, several forward buying heuristics have been developed that utilize the Newsvendor model to improve the effectiveness of commodity procurement programs (Gavirneni & Morton, 1999; Manikas, Chang, & Ferguson, 2009). Similarly, where firms are required to acquire emissions allowances on the open market, a strategy to forward buy allowances when market prices are favorable and bank the allowances as "inventory" for use in future periods may reduce a firm's compliance costs. The procurement and disposition of emissions allowances differs from commodity purchases primarily because no physical item is bought, stored, or may deteriorate. In addition, commodity purchases require lead-time considerations for delivery of the commodities prior to use. As noted in Manikas, Chang, & Ferguson (2009), commodity purchases may be limited to firms that can procure the required minimum quantities. Emission allowance purchases do not have minimum or multiple purchase and selling quantities, allowing all firms to benefit from forward buying of them. Ultimately, this study demonstrates that an enhanced Newsvendor model for emissions allowance forward buying and current period production planning can increase firm performance.

The next section discusses the theoretical basis for this study. The third section presents the proposed heuristic. The fourth section describes the simulation conducted using empirical emissions allowance market data to test the effectiveness of the new heuristic. The fifth and sixth sections respectively present the results of the simulation and the managerial insights of the study. The final section summarizes the study's conclusions.

2. THEORETICAL DEVELOPMENT

The U.S. Acid Rain Program (ARP) was the first fully implemented cap and trade emissions regulation system (Kroes, Subramanian, & Subramanyam, 2012). The program, which focuses on reducing the emissions of sulfur dioxide (SO_2) generated during electricity production, has utilized cap and trade regulation successfully to reduce emissions by 67% compared to 1980 levels (EPA, 2009). Firms regulated by the ARP complied with the program's emission restrictions by either acquiring allowances to offset their emissions or reducing their emissions levels. The ARP's successful reduction of pollutant emissions through the use of cap and trade has spawned a number of similar regional, national, and international programs, including the California Cap and Trade Program, the European Union Emissions Trading System (EU ETS) and the New Zealand Emissions Trading Scheme; all of which focus on reducing CO_2 emissions (Marcacci, 2013; Ranson & Stavins, 2012).

The EU ETS, which is the most mature of the currently enacted international CO_2 cap and trade programs, provides an example of the likely format for future regulations. The program established a carbon market in its first phase (2005 to 2007); however, the number of freely allocated allowances exceeded the demand, and the allowance market price dropped to essentially zero. Despite a 6.5% reduction in the total emissions cap in the EU ETS's second phase (2008 to 2012), the market price of allowances again dropped substantially due to reduced demand resulting from the global economic recession. At the beginning of 2013, the EU ETS entered its third phase, in which the free allocation of allowances is being replaced gradually by auction markets as the primary mechanism for allowance acquisition (European Union, 2013). CO_2 allowance auctions now occur several times each week, making the open market acquisition of allowances relatively straightforward for regulated entities (by contrast, SO_2 allowance auctions occur only once per year under the ARP (EPA, 2002)). During 2013, the percentage of allowances acquired via auction represented over 40% of the total number of issued allowances (European Union, 2014). Correspondingly, during this phase of the EU ETS, the total emissions cap will be decreased by 1.74% annually until 2020 (European Union, 2008). At the initiation of this study, the EU ETS CO_2 allowance market has steadied as prices during this phase have remained relatively stable compared to the precipitous drops experienced during the first two phases (IntercontinentalExchange, 2013).

A key tenant of cap and trade systems is that all players are required to purchase emissions allowances on regulated open markets. The transparency of the market based system reduces the likelihood that one player may gain an advantage from information asymmetry. The EU ETS explicitly prohibits participants from taking any actions to manipulate the market. Specifically, the EU ETS requires that emissions allowance purchases must be legitimate and based on defensible production estimates for the firm, i.e., a firm may not arbitrarily buy an unlimited number of allowances in an attempt to influence the market (European Union, 2010).

Cap and trade programs incorporate mechanisms that gradually increase the scarcity of allowances to achieve lasting, sustainable emissions reductions (European Union, 2013). One of the most common mechanisms is a gradually reduced total emissions cap. Additionally, while most cap and trade programs (including both the ARP and the EU ETS) initially distribute a portion of allowances to regulated firms free of charge (commonly referred to as grandfathering), the percentage of free allowances usually is decreased over the course of these programs to also increase the scarcity of allowances. For example, firms impacted by the U.S. Acid Rain Program were freely allocated allowances equal to approximately 85% of the firms' historical emission levels' released during a baseline period. However, new emissions sources that have come online after the start the program are not allocated any free allowances (US EPA, 2010). Similarly, firms impacted by the EU ETS were initially freely allocated 80% of the firm's allowance requirement at the beginning of Phase 3 of the program in 2013. However, the number of freely allocated allowances is decreasing annually so that grandfathering will only cover 30% of a firm's requirement in 2020 (European Commission, 2014). Subsequently, as the emissions allowances become scarcer, the market prices of allowances are expected to increase over the long run, triggering further investments in process improvements (European Union, 2013). However, in the short run, other factors, including the state of regional and global economies, can lead to fluctuations in the demand for allowances, which has been shown to impact the market prices of emissions allowances substantially. These market fluctuations, similar to those experienced in many commodity markets, are a primary motivation of this study into the applicability of forward buying strategies to the emissions allowance procurement problem.

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The practice of forward buying materials to take advantage of favorable pricing has been applied to a number of prior operational scenarios. Two seminal works, Magirou (1982) and Golabi (1985), develop methods in which a material is purchased and held as inventory for future use when the material's current price is low enough, compared to its forecasted future price, such that the cost savings resulting from purchasing the material and holding it as inventory offset the increased holding costs. A key difference between these two works is that Magirou limits the storage capacity of the material, and Golabi does not. Golabi's approach is used in this study because the allowances are not physical goods; hence, the allowance storage capacity is unconstrained. Golabi's method assumes that demand is deterministic when it compares the costs of purchasing a material when demand is realized versus the potential cost savings of purchasing a material and holding it as inventory until needed. Manikas et al. (2009) address this limitation with their GOGA heuristic; GOGA utilizes Golabi's method to determine the number of periods for which to forward buy and then applies a modification of Gavirneni's (2004) Newsvendor model to determine the production level for the current period. Gavirneni's modified Newsvendor equation, which assumes stochastic non-perishable demand in the current period, considers the current purchase cost, the expected purchase cost, and the cost of holding overage units as inventory (rather than the salvage costs of scrapping the overage) to determine the optimal order up to level. The combination of Golabi (1985) and Gavirneni (2004) used in GOGA has been shown to be effective at improving firm profits, though it is limited because it treats only the current period demand as stochastic (all future demand is assumed to be deterministic and purchase amounts for forward buys are set equal to the expected mean demand).

Ideally, a zero-emissions strategy is the optimal operational policy for firms attempting to minimize the impact of allowance cap and trade regulation on their businesses. However, most firms are likely to adopt compliance strategies that combine emissions reductions with emissions permitted through the surrender of acquired allowances (European Union, 2013). For these firms, this study proposes that an advanced Newsvendor based allowance acquisition and production strategy, developed from existing forward buying strategies, may lead to substantial cost reductions.

The use of a Newsvendor approach in this study is motivated by previous research efforts which have demonstrated that modified versions of the Newsvendor equation can be employed to improve environmental performance. Raz, Druehl, andd Blass (2013) used this approach to assess the environmental impacts of product design innovation decisions. Relatedly, Rosič and Jammernegg (2013) also utilize a Newsvendor approach to investigate economic and environmental performance in their examination of the impact of a decision to source a product domestically versus locally on transport related emissions. To the best of this study's authors' knowledge, this effort presents the first Newsvendor based forward buying and production decision heuristic specifically designed to address the emissions allowance procurement problem.

3. PROBLEM STATEMENT AND PROPOSED HEURISTIC

Existing forward buying heuristics were designed for commodity procurement, which entails factors such as lead-time for shipping of the commodities, storage requirements, and holding costs. Conversely, emission allowances are not physical objects, and may be bought and sold in any quantity with essentially zero lead-time delay from purchase to possession. As a result of these differences, existing commodity forward buying methods do not explicitly address production planning and emissions allowance management strategies for firms operating under cap and trade regulation. This section discusses the details of the problem and the heuristic developed to address this situation.

3.1 Problem Statement

A firm operating under a cap and trade regulatory system must determine how many allowances to purchase during each planning period to offset the emission of a regulated pollutant (e.g., CO_2). The quantity of allowances to purchase must reflect the number of periods for which the firm is buying allowances, the ideal production quantity in each of those periods, and the available inventory of allowances. A firm must first decide whether to buy more allowances than it requires in the current period to take advantage of anticipated allowance market price increases (i.e. forward buying). For forward buying to occur, the expected price savings resulting from purchasing allowances and holding them until they are needed must outweigh the costs of holding allowances in "inventory" until needed. However, in the case of allowances, the holding costs are essentially the costs of the capital invested in the allowances rather than traditional inventory carrying costs. Next, the ideal production quantities in each period need to be determined based on demand forecasts, the product costs, and the costs of emissions allowances (that otherwise would be an externality) corresponding to the production quantity. Additionally, the free market nature of a cap and trade program means that firms need to decide if they should sell excess allowances when the allowance price in the next period is forecasted to drop below the current value of inventoried allowances.

3.2 Assumptions

The proposed forward buying heuristic is designed for a general cap and trade regulatory scenario in which a firm is required to acquire and surrender allowances to offset pollutant emissions generated during the production of goods. Two variations of the model are examined: one for perishable products and one for non-perishable products. The heuristic does allow for the free allocation of a portion of the required allowances, even though this practice typically is limited in mature regulatory programs. To this end, the following assumptions are made:

Condition 1: Finished goods demand is stochastic with a known distribution.

Condition 2: The purchase prices of emissions allowances exhibit market fluctuations beyond the influence of the firm.

Condition 3: Fabrication of finished good products must be done prior to realizing that period's demand, and the period length is insufficiently long to produce additional sellable goods should demand exceed on-hand inventory.

Condition 4: The firm does not produce viable substitute products to fill demand; therefore, any unmet demand is filled by another player in the market (no backorders). If unmet demand may be filled at any future time period without loss of goodwill or revenue the problem can be mathematically reduced to a Silver-Meal algorithm as done in Şenyğit and Erol (2010).

Condition 5: Demand is independent between periods (i.e., because there are no backorders, demand in one period does not affect other periods.)

Condition 6: Pollutant emissions increase linearly with production quantity.

Condition 7: Emissions allowances may be purchased or sold each period on open spot markets at the current auction market price. Allowances may also be acquired at zero cost through free allocation programs.

Condition 8: Each period, the emissions allowances that the firm owns are revalued at the average price paid for the allowances.

Condition 9: Emissions allowance purchases are be legitimate and not made in an attempt to influence the market (European Union, 2010).

3.3 Newsvendor Production Planning with Emissions Allowance Forward Buying

The proposed heuristic builds on aspects of several previous buying methodologies (Gavirneni, 2004; Golabi, 1985; Manikas et al., 2009). At the beginning of each period, a variation of Golabi's (1985) forward buying algorithm is applied to determine the number of periods for which to forward buy allowances. Further, the holding cost in the modified version of Golabi's equation is set to be the cost of capital only, as there is no physical product subject to shrinkage, damage, obsolescence, and perishability with emission allowances. A modified Newsvendor equation then is used to determine the current production level. In contrast to GOGA, which uses the expected mean demand to determine future requirements, when allowance forward buying takes place, the proposed heuristic reapplies the modified Newsvendor model to estimate the current and future emissions allowance requirements (which serve as the order up to level for allowance purchases). Another key difference between GOGA and the proposed heuristic is that

Table 1: Model Notation

Symbol	Description
τ_n	The allowance threshold price in period *n*. A decision is made to forward buy allowances for period *n* when the current spot market price for allowances is below τ_n.

x	The emissions allowance spot market price.
$F(x)$	The forecasted cumulative emissions allowance price distribution for each period.
h_e	The cost to hold an emissions allowance for one period.
p	The selling price of the finished good per unit to the end consumer.
c	The Cost of Goods Sold (COGS) per unit excluding the emissions allowance cost.
s	Salvage value for perishable inventory at the end of the period.
A	The order up to level for emissions allowances in the current period. In each period, additional allowances are procured via the open market to bring the allowance inventory up to A.
a	The number of emissions allowances required to produce one unit of finished goods.
e	The cost to purchase the emissions allowances required to produce one unit of finished goods in period 0, the current period. This amount is scaled to the number of FG units per allowance. E.g., if producing 100 units produces 1 ton of CO_2 and the market price of an allowance to emit one ton is \$4.21, e will be \$0.421.
$\bar{e}$	The expected cost to purchase the emissions allowances required to produce one unit of finished goods in period 1.
h_{fg}	The finished goods holding cost for one period.
g	Goodwill cost of not fulfilling demand (per unit).
n	Number of periods beyond the current period to forward buy.
y_i	The order-up-to level for period i $(i=0,\ldots n)$, where in period 0 the order-up-to level is the number of finished goods ready for sale. For future periods, this term indicates the expected production level, which is not actually produced but rather is used to calculate the number of allowances to forward buy for future use in that period.
Φ^{-1}	The inverse CDF of demand.
D	Realized demand for period 0.

the new method allows a firm to sell excess allowances on the open market when the market conditions are favorable. The heuristic, which is designated as Newsvendor Production Planning with Emissions Allowance Forward Buying (NPPAFB), is applied repeatedly at the beginning of each planning period to a rolling planning horizon. The stimulus for this approach originated from Easton and Rossin's (1996) method, which evaluates a Newsvendor model each period while treating the planning horizon in a period as an "independent epoch." The notation for the models utilized in the NPPAFB heuristic is detailed in Table 1.

As noted above, NPPAFB initially applies a modification of Golabi's (1985) formulation that calculates a series of price thresholds, based on future commodity price forecasts and holding costs of emission allowances. The thresholds determine the number of periods for which commodities will be forward bought. For CO_2 allowances, the modified version of Golabi's formulation is used to examine a forecast of emissions allowance future prices that is compared against the cost of capital invested in allowances that are held for use in future periods. Golabi's equation accounts for the likelihood that the next period purchase price will be less than the current price and the financial benefit of locking in the prior price minus the holding costs of one period. The modification of Golabi's equation ultimately calculates an emission allowance threshold price per unit such that buying ahead *n* periods is optimal. Explicitly, equation (1) below uses the emissions allowance spot market price (x), a forecasted cumulative allowance price distribution for each period ($F(x)$), and the cost of capital for holding one emissions allowance for one period (h_e). The price distributions ($F(x)$) are predictions of a future price distributions forecasted from historical prices. A current allowance market price below τ_n is a signal to forward buy allowances for future use in period n.

$$\tau_{n+1} = \int_0^{\tau_n} x dF(x) + \int_{\tau_n}^{\infty} \tau_n dF(x) - h_e \quad \textbf{(1)}$$

Next, NPPAFB applies a modification of the Newsvendor model to determine the finished goods order up to level in the current period, which dictates the number of emissions allowances required in the current period. Although goods are produced only in the current period, the Newsvendor model is reapplied to future periods to determine the expected production levels in those periods for which allowances are being forward bought (determined from [1]); this estimated production level is used to calculate the number of additional emissions allowances to procure in the current period and hold for future use. This approach differs from GOGA, in which Manikas et al. (2009) simply procure the mean demand level for each of the future periods for which they are forward buying commodities.

Two modified versions of existing Newsvendor models are used in the NPPAFB heuristic; one for a scenario in which the finished goods are non-perishable and can be held to meet future demand, and one for perishable goods that are discarded at the end of each period. The Newsvendor approach was selected because of the model's ability to determine the optimal production and inventory levels, while ensuring the appropriate customer service levels that minimize costs (Rogers & Tsubakitani, 1991). Gavirneni's (2004) approach for non-perishable goods calculates the underage costs as the finished good's unit selling price (p) minus the current unit cost (c), and the overage costs as the current unit cost (c) plus the cost to hold one unit in inventory for one period (h_{fg}) minus the expected unit cost in the next period ($\overline{c}$). Gavirneni's Newsvendor model, with notation to reflect finished good holding rather than commodity holding costs, is expressed as:

$$y = \Phi^{-1}\left(\frac{p-c}{p+h_{fg}-\overline{c}}\right) \quad \textbf{(2)}$$

This model is tailored to the emissions allowance scenario by additionally considering the cost of the emissions allowances required to produce one unit of finished goods (e), the expected allowance cost in the next period ($\overline{e}$) and the unit goodwill costs (g). Under some circumstances, goodwill may be set to zero, as it is difficult to quantify brand and customer effects beyond monetary options (free shipping, discounts, coupons, etc.). Specifically, for non-perishable goods, the underage costs are calculated as the unit selling price (p) minus the current unit cost (c) minus the unit emissions cost (e) plus the unit goodwill cost. The overage costs are computed as the current unit cost (c) plus the cost to hold one unit in inventory for one period

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(h_{fg}) plus the unit emissions cost (e) minus the expected unit emissions cost in the next period ($\bar{e}$). These last two emissions terms account for the current versus expected purchase price of emissions allowances. The holding cost for one unit of inventory takes into account the material, labor, and emissions costs used to produce that finished good. The material and labor costs are assumed not to vary substantially from period to period, therefore, the formulation includes variable emissions costs ($\bar{e}$) rather than variable material costs ($\bar{c}$). The modified Newsvendor is expressed as:

$$y = \Phi^{-1}\left(\frac{p-c-e+g}{p+h_{fg}-\bar{e}+g}\right) \quad \textbf{(3)}$$

For perishable finished goods that are discarded at the end of the period, NPPAFB employs a modified version of the traditional Newsvendor formula. The finished goods holding costs and the expected cost of emissions allowances in the next period are no longer considered; however, the salvage value of the unsold finished goods is now considered. The salvage value (*s)* may be zero, positive or negative (indicating a disposal cost for excess units at the end of the period). The modified Newsvendor equation for perishable goods is expressed as:

$$y = \Phi^{-1}\left(\frac{p-c-e+g}{p-s+g}\right) \quad \textbf{(4)}$$

3.4 The NPPAFB Heuristic: Detailed Order of Events

Within each period, NPPAFB follows the steps detailed below and in Figure 1 to determine the current period's allowance procurement order-up-to-level and the production order-up-to-level:

1. Forecast future emissions allowance prices through the end of the planning horizon to be used in (1), (3) and (4), as appropriate.

2. For the current period (period 0), calculate the order-up-to quantity y_0 of finished goods to produce and stock using (3) for non-perishable products or (4) for perishable products.

3. Use (1) to calculate *n*, the number of additional periods for which emissions allowances should be bought (i.e., *n* values greater than 0 represent a decision to forward buy allowances for use against production emissions allowance requirements in future periods).

If $n > 0$, for periods i=1 through *n*, calculate y_i, the estimated production level in each future period, based on repeated application of (3) for non-perishable products or (4) for perishable products, which is used to estimate the quantity of allowances required for the expected production levels of finished goods in future periods.

Let $Y = y_0 + \sum_{i=1}^{n} y_i$, which represents the total expected units of finished goods that will be produced in the current period and the future periods for which allowances will be forward bought. From *Y*, the emissions allowance order-up-to inventory level *A* is calculated using $A = aY$, which is rounded up to the nearest whole allowance, as partial allowances cannot be purchased.

4. Any allowances obtained through free allocation programs (i.e. grandfathered allowances) are added to the allowance inventory.

5. If the current inventory of allowances is less than *A*, buy the required additional allowances on the spot market.

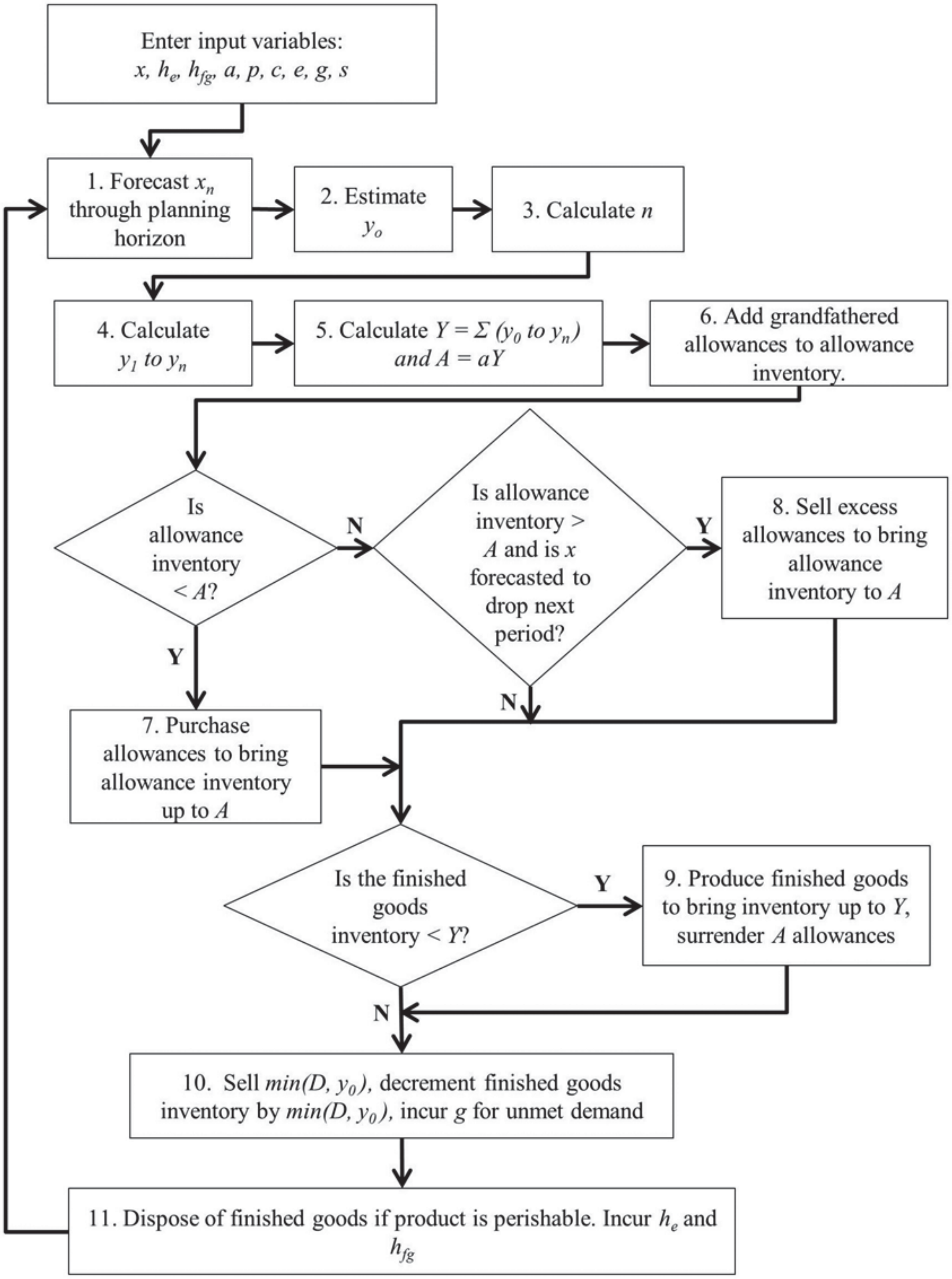
6. If the firm's inventory of allowances is greater than *A* and the current average price paid per allowance [minus one period's cost of capital] is greater than the forecast for next period's allowance market auction price, sell all excess allowances on the spot market.

If the current finished goods inventory is less than y_0, produce the finished goods required to bring the inventory up to y_0 and surrender the appropriate number of emission allowances to the regulatory authority.

Let *D* be the demand realized for the period. Sell the minimum of *D* and y_0. Unmet demand is lost. Goodwill penalties, if any, are assessed for the unmet demand. For non-perishable finished goods, the finished goods inventory position is decremented by $min(D,\ y_0)$.

7. For perishable goods, each unsold unit of finished goods is salvaged or disposed resulting in period ending inventory of zero. For non-perishable goods, each remaining unsold unit of finished goods incurs a holding cost based on the COGS and the firm's inventory carrying cost. Each unused allowance incurs a holding cost based on the average cost of the past allowance purchases (regardless if those units may have been sold in a previous period) and the firm's cost of capital.

Figure 1: NPPAFB: Order of Events



Enter input variables:
x, he, hfg, a, p, c, e, g, s
1. Forecast xn through planning horizon
2. Estimate yo
3. Calculate n
4. Calculate y1 to yn
5. Calculate Y = Σ (y0 to yn) and A = aY
6. Add grandfathered allowances to allowance inventory.
Is allowance inventory < A?
N
Is allowance inventory > A and is x forecasted to drop next period?
Y
8. Sell excess allowances to bring allowance inventory to A
Y
7. Purchase allowances to bring allowance inventory up to A
N
Is the finished goods inventory < Y?
Y
9. Produce finished goods to bring inventory up to Y, surrender A allowances
N
10. Sell min(D, y0), decrement finished goods inventory by min(D, y0), incur g for unmet demand
11. Dispose of finished goods if product is perishable. Incur he and hfg

4. EMPIRCAL EVALUATION OF THE HEURISTIC

Simulation is used to empirically test the effectiveness of the NPPAFB heuristic against three other planning methods for non-perishable and perishable finished goods. The first method, designated as the Base method (BASE), represents a simplistic compliance and production planning system in which allowances are not forward bought and the finished goods production order up to level in a period is set at the mean expected demand. The second method, designated as Newsvendor Production Planning (NPP), applies equation (3) for non-perishable goods or equation (4) for perishable goods at the beginning of each period to determine the production order up to level. The production level then is used to calculate the number of emissions allowances required in the current period. Like BASE, NPP does not forward buy emissions allowances. Finally, NPPAFB is compared against the GOGA method which also incorporates allowance forward-buying but differs from NPPAFB in that the future allowance purchase volume is based on the expected mean demand (rather than a Newsvendor determined amount) and that the selling of excess allowances is not permitted. The simulation results are used to compare the total profits and emissions allowance expenditures that result from the application of NPPAFB, BASE, NPP, and GOGA to scenarios incorporating a variety of business conditions.

Three separate simulations are conducted using three distinct sets of allowance market price data: the first simulation utilizes actual data from the current phase of the EU ETS (Phase 3), which began on January 1, 2013 and the last two simulations use hypothetical data models based on two divergent predictions for the EU ETS allowance price in 2020 – an upward trending price prediction of ~U(€18, €26) and a downward trending price prediction of ~U(€0.01, €0.99)) per allowance (Committee on Climate Change, 2009). Several factors contributed to the decision to focus on data related to the EU ETS. First, despite the U.S. Acid

Rain Program's comparative maturity, historical data from the Acid Rain Program is limited as the program conducts allowance auctions only once per annum, while the EU ETS conducts multiple auctions each week. Next, the frequency of the EU ETS auctions allows firms to procure or sell emissions allowances with relative ease compared to the Acid Rain Program. Finally, the decision was made to include only actual data from Phase 3 of the EU ETS because of the CO_2 market instability that occurred during the program's prior two phases.

4.1 EU ETS Phase 3 Actual Allowance Price Data

At the time of this study, the Phase 3 EU ETS allowance auctions have been in operation from January 2, 2013 until February 12, 2014. Therefore, NPPAFB is tested using the weekly emissions allowance prices over this 56-week period. The weekly EU ETS CO_2 allowance prices during Phase 3, depicted in Figure 2, show that that the market experienced some volatility during the sample period. The initial allowance price of €6.69 per allowance was the peak market price experienced during the sample period. Subsequently, the market price dropped to a low of €2.78 which was followed by an increase to €6.50 per allowance at the end of the sample period.

4.2 Simulated Future EU ETS Allowance Price Data

For each of the 10,000 simulated upward trending price and 10,000 downward trending price iterations within the last two simulation runs, a new hypothetical set of price data is bootstrapped using a random walk procedure. The procedure starts with the February 12, 2014 actual EU ETS allowance price and creates an additional 306 weeks of simulated price data out to January 2020. To create a new week of simulated price data, the procedure starts with the previous week's price and adds (or subtracts) a component calculated as the weekly straight line price trend from the actual allowance price on February 12, 2014 to the predicted prince in 2020

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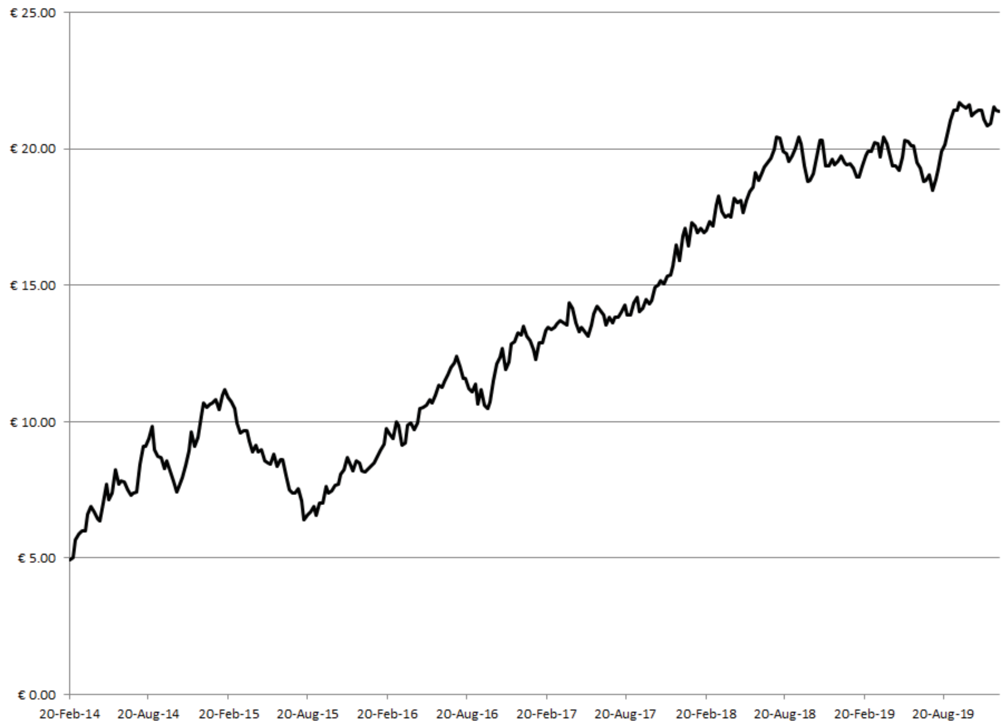
Figure 2: EU ETS Phase 3 Allowance Market Prices (January 2, 2013 to February 12, 2014)

Source: IntercontinentalExchange, 2014

(either ~U(€18, €26) or ~U(€0.01, €0.99)) plus a random component ranging between -3 and +3 standard deviations of the EU ETS Phase 3 prices variation exhibited between January 2013 and February 2014. Examples of an upward trending price dataset and a downward trending price dataset are shown respectively in Panels A and B of Figure 3.

Figure 3: Examples of Bootstrapped Datasets

Panel A: Example of simulated upward trending allowance price data through January 2020



Panel B: Example of simulated downward trending allowance price data through January 2020

4.3 Scenario Creation

Ten-thousand unique datasets are created for each of the three simulation runs. Each dataset contains a randomly generated mix of product conditions including Product Perishability (Yes / No), Product Cost ($ / unit), Product Selling Price ($ / unit), Product Goodwill ($ / unit), Emissions Allowances required (# / unit), Cost of Capital (%), Mean Demand (units) and Standard Deviation of Demand, which are held constant over an individual dataset's time frame (i.e. 56 weeks in the first simulation and 306 weeks in the second and third simulations). Additionally, each perishable product dataset contains a randomly generated Product Salvage Value ($ / unit) that also is constant across the dataset's time frame. Additionally, for each dataset, the dataset's mean and standard deviation of demand is used to randomly generate demand data for each week of allowance price data that is being tested (i.e. 56 weeks in the Phase 3 analysis and 306 weeks for both the upward and downward trending price runs). The distributions of the simulation parameters are described in Table 2.

The NPPAFB and GOGA heuristics each require a forecast of future allowance market prices to determine the forward buying price thresholds, which is computed using a variation of the simple linear forecasting method proposed by Chatfield (2000). The forecast for the next period is calculated as $F_{t+1} = \alpha_t + \beta_t * t$, where α_t is the local intercept based on the current allowance market price, and β_t is the local slope, which is calculated using the two most recent data points. A naïve forecast based on F_{t+1} is used to determine the local intercept and slope for forecasts two or more periods out because the actual market data is not known for future periods. It is not suggested that this is necessarily the best possible allowance price forecasting method, but rather this method was selected due to its simplicity and ease of implementation.

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Table 2: Parameter Distributions for Simulation Replications

Variable	**Distribution**
Product Cost ($ / unit)	~U($1, $50)
Product Selling Price ($ / unit)	~U(*c* + $25, *c* + $200)
Product Salvage Value ($ / unit)	~U(-$10, *c* - $10)
Product Goodwill ($ / unit)	~U($0, *p*)
Allowances Required (# / Finished Good Unit)	~U(0.2, 5)
Cost of Capital (%)	~U(5%, 12%)
Mean Demand (units)	~U(1000, 3000)
Standard Deviation of Demand	~U(Mean Demand / 4, Mean Demand * ¾)

In each simulation run, the NPPAFB, BASE, NPP, and GOGA heuristics each are applied to all of the 10,000 datasets. Applying all four methods to each dataset eliminates the possibility that outlying datasets may skew the results of one of the methods. The relative performance of the four heuristics is assessed by examining the emissions allowance purchase costs and the total profits generated within the three simulation runs.

5. RESULTS AND DISCUSSION

The results from the simulation tests of the four heuristics, detailed in Tables 3, 4, and 5, show that NPPAFB outperforms BASE, NPP, and GOGA for both non-perishable and perishable finished goods over a range of business conditions. Paired sample T-Tests are used to statistically compare the four allowance acquisition methodologies. Compared against all three methods, the simulation results show that the NPPAFB heuristic improves the overall

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Table 3: Simulation Results – ETS Phase 3 Price Data

	Newsvendor Production Planning with Allowance Forward Buying (NPPAFB)	**Base Method (BASE)**	**Newsvendor Production Planning (NPP)**	**Golabi / Gavirneni with Newsvendor Production Planning (GOGA)**
Non-Perishable Products (n=4,983)				
Average Total Profit	€ 11,598,614	€ 8,119,509	€ 11,527,850	€ 11,569,729
(% Difference vs. NPPAFB)	-	(-30.0%)***	(-0.6%)***	(-0.2%)***
Average Allowance Effective Purchase Cost[1]	€ 3.96	€ 4.62	€ 4.64	€ 4.54
(% Difference vs. NPPAFB)	-	(+16.7%)***	(+17.0%)***	(+14.7%)***
Perishable Products (n=5,017)				
Average Total Profit	€ 13,464,054	€ 8,233,396	€ 12,490,659	€ 12,545,614
(% Difference vs. NPPAFB)	-	(-38.8%)***	(-7.2%)***	(-6.8%)***
Average Allowance Effective Purchase Cost[1]	€ 3.95	€ 4.62	€ 4.64	€ 4.55
(% Difference vs. NPPAFB)	-	(+17.2%)***	(+17.5%)***	(+15.2%)***

Significance vs. NPPAFB Method, *⇒p< 0.05; **⇒p < 0.01; ***⇒p< 0.001 based on a Paired Samples two-tail T-Test.

[1]Average Allowance Effective Purchase Cost = ([Total Allowance Purchase Costs + Total Allowance Holding Costs – Total Allowance Sales Revenue] / [# of Allowance used for production])

Table 4: Simulation Results – Bootstrapped Data upward trend to 2020

	Newsvendor Production Planning with Allowance Forward Buying (NPPAFB)	**Base Method (BASE)**	**Newsvendor Production Planning (NPP)**	**Golabi / Gavirneni with Newsvendor Production Planning (GOGA)**
Non-Perishable				

Products (n=5,025)				
Average Total Profit	€ 61,495,330	€ 41,966,505	€ 60,840,759	€ 61,345,679
(% Difference vs. NPPAFB)	-	(-31.8%)***	(-1.1%)***	(-0.2%)***
Average Allowance Effective Purchase Cost[1]	€ 12.12	€ 13.41	€ 13.38	€ 12.45
(% Difference vs. NPPAFB)	-	(+10.7%)***	(+10.4%)***	(+2.7%)***
Perishable Products (n=4,975)				
Average Total Profit	€ 70,630,010	€ 42,954,450	€ 65,403,544	€ 65,899,386
(% Difference vs. NPPAFB)	-	(-39.2%)***	(-7.4%)***	(-6.7%)***
Average Allowance Effective Purchase Cost[1]	€ 11.96	€ 13.34	€ 13.22	€ 12.30
(% Difference vs. NPPAFB)	-	(+11.5%)***	(+10.5%)***	(+2.8%)***

Significance vs. NPPAFB Method, *⇒p< 0.05; **⇒p < 0.01; ***⇒p< 0.001 based on a Paired Samples two-tail T-Test.

[1]Average Allowance Effective Purchase Cost = ([Total Allowance Purchase Costs + Total Allowance Holding Costs – Total Allowance Sales Revenue] / [# of Allowance used for production])

Table 5: Simulation Results – Bootstrapped Data downward trend to 2020

	Newsvendor Production Planning with Allowance Forward Buying (NPPAFB)	**Base Method (BASE)**	**Newsvendor Production Planning (NPP)**	**Golabi / Gavirneni with Newsvendor Production Planning (GOGA)**
Non-Perishable Products (n=4,958)				
Average Total Profit	€ 65,127,657	€ 45,156,047	€ 64,376,385	€ 64,521,797
(% Difference vs. NPPAFB)	-	(-30.7%)***	(-1.2%)***	(-0.9%)***
Average	€ 2.49	€ 3.87	€ 3.87	€ 3.60

Allowance Effective Purchase Cost[1]				
(% Difference vs. NPPAFB)	-	(+55.4%)***	(+55.2%)***	(+44.5%)***
Perishable Products (n=5,042)				
Average Total Profit	€ 77,313,501	€ 46,703,814	€ 71,184,356	€ 71,330,898
(% Difference vs. NPPAFB)	-	(-39.6%)***	(-7.9%)***	(-7.7%)***
Average Allowance Effective Purchase Cost[1]	€ 2.49	€ 3.90	€ 3.89	€ 3.62
(% Difference vs. NPPAFB)	-	(+56.4%)***	(+56.0%)***	(+45.3%)***

Significance vs. NPPAFB Method, *⇒p< 0.05; **⇒p < 0.01; ***⇒p< 0.001 based on a Paired Samples two-tail T-Test.

[1]Average Allowance Effective Purchase Cost = ([Total Allowance Purchase Costs + Total Allowance Holding Costs – Total Allowance Sales Revenue] / [# of Allowance used for production])

profitability while reducing emissions allowance expenditures. Due to the large sample size of each simulation group (n = 10,000, consisting of approximately 5,000 cases for perishable products and 5,000 cases for non-perishable products), the statistical power for each of the T-Tests exceeds 99%.

5.1 Impact on Profitability

NPPAFB consistently generated higher profits compared to the three other methods. NPPAFB was superior to BASE, NPP, and GOGA respectively in 99.8%, 97.9%, and 84.4% of the tested datasets. As described above, all four planning methods were applied to each dataset; therefore, paired samples T-Tests can be employed to statistically compare the performance of the three heuristics. These tests find that compared to NPPAFB, each of the three other methods generate statistically lower profits ($p < 0.001$) for both non-perishable and perishable products. Compared to the simplistic BASE method, all three methods generate substantially higher profits for both product types, which reinforces the well-established advantage of Newsvendor based planning models. Though the improvements in the profits generated by NPPAFB versus NPP and GOGA are significantly higher for both product types across all three allowance price simulations; the average improvement in profitability for non-perishable products amounts only to a difference ranging from 0.2% to 1.2%. Comparatively, for perishable products, NPPAFB generates profits approximately seven percent higher than NPP and GOGA across all three simulations. The superiority of NPPAFB's performance for perishable products is likely because the per unit cost of finished goods are typically lower under NPPAFB due to the lower allowances costs which lowers holding costs compared to goods created using allowances purchased at higher market price points. These lower costs in turn also increase the relative margin of incurred costs which are recovered when a perishable product is disposed of or salvaged.

5.2 Impact on Emission Allowance Costs

While NPPAFB does improve the profitability for firms operating under cap and trade regulation, its most managerially important impact is on the costs of emissions allowances. As shown in Tables 3, 4, and 5, for both non-perishable and perishable finished goods in all three allowance price scenarios, the average per allowance purchase costs under BASE and NPP essentially are equal while the cost paid under GOGA (in which allowances are forward bought) tends to be slightly lower. However, compared to all three of these methods, the effective cost of allowances under NPPAFB (which includes the holding costs and the revenue generated when market conditions dictate allowances to be sold) drops significantly ($p < 0.001$).

The ability of GOGA and NPPAFB to reduce the per unit allowance compliance costs compared to BASE and NPP is clearly a benefit of allowance forward buying. Correspondingly, NPPAFB's improvement relative to GOGA results from the NPPAFB's incorporation of allowance selling. This is supported by the results seen in the three market price simulations – the reduction in allowance cost is greatest in the downward trending allowance price simulation; which incorporates scenarios in which there is likely to be more selling of allowances under NPPAFB. In line with this, the per allowance cost improvement under NPPAFB versus GOGA is the smallest in the upward trending price simulation, in which the least amount of allowance selling is likely to occur.

5.3 Numerical Example

Detailed carbon cost data for individuals firms is difficult to attain due to the infancy of carbon trading schemes; however the following example illustrates the potential impact of NPPAFB on a firm's financial performance. In 2013, the electric utility Duke Energy Corporation was one of the largest emitter of CO_2 in the United States. In that year, Duke Energy reported a net income of \$2.7 billion on operations that emitted 136 million tons of CO_2 (Duke Energy Corporation, 2014a & 2014b). Assuming that the 2013 EU ETS CO_2 allowances prices are representative of the prices that a hypothetical U.S. based system would experience, Duke Energy would have been required to incur an additional expense of \$823 million to acquire the required allowances using a GOGA based buying strategy. The cost to acquire allowances would decrease to \$715 million if they instead used NPPAFB to acquire allowances. Presuming that the allowance expenditures directly impact Duke Energy's net profits, the application of NPPAFB would improve the firm's profitability \$108 million during 2013 (a 5.9% improvement versus GOGA). In particular, this example highlights the impact that improved allowance acquisition strategies can have on emissions intensive industries in which the costs of compliance are large relative to the profit margins.

6. MANAGERIAL INSIGHTS

The results of this study show that under real world scenarios, the NPPAFB heuristic can be expected to decrease the costs of compliance and subsequently improve profitability for firms operating under cap and trade regulation. From a practical standpoint, regulated firms should primarily strive to reduce and eliminate emissions to avoid the costs of emissions allowances (Gunasekaran & Spalanzani, 2012). However, when firms have exhausted their ability to avoid emissions and must acquire allowances, they need to carefully develop a strategy that minimizes the impact of environmental compliance costs on their business performance.

The simulation results show that the application of any of the three modified Newsvendor models to the production decision generates the majority of the improvement in profitability compared to the BASE method. Although the NPPAFB does not necessarily dominate NPP and GOGA across all of the simulations from a profit perspective, the value of NPPAFB should not be discounted; the findings do show that in the majority of examined cases, across a variety of allowance price behavior scenarios, the additional actions permitted under NPPAFB significantly improves on the profitability and allowance costs generated by using either BASE, NPP, or GOGA. These findings are particularly true for perishable goods.

Specific to the proposed NPPAFB heuristic, firms need to consider if their emissions allowance needs are substantial enough to warrant the time and expense of managing a complex forward buying and selling program. The assessment of whether a firm should employ NPPAFB should be based on a careful analysis of the specific conditions experienced by the firm. First, the overall nature and volatility of the allowance market should be examined. Particularly, it is important to note that while the emissions cost savings generated when NPPAFB sells allowances on the market is greatest when market prices are trending downward, similar cost savings can be obtained in practically any scenario that includes several successive periods of declining prices. Next, the specific characteristics of the regulated product need to be considered. If the finished good in question is perishable, the results of the simulations show that the case for implementing NPPAFB over NPP or GOGA is stronger compared to that for non-perishable products. Additionally, the level of emissions generated in the production of a finished good should also be examined. As the number of allowances per unit increases, the case for implementing NPPAFB becomes more compelling due to the expected reduction in the per unit allowance costs. Conversely, if the emissions allowances required represent a trivial portion of a firm's overall costs, a less complex procurement strategy might be more appropriate.

7. CONCLUSIONS

This study has developed an innovative new heuristic, which combines a forward buying decision algorithm with modified Newsvendor formulations, to enhance emissions allowance procurement for firms that generate regulated pollutants as a byproduct of their finished goods manufacturing processes. NPPAFB's flexibility to accommodate both perishable and non-perishable products assures that it can be applied to virtually any scenario in which a firm operates under a market based cap and trade regulatory program. The results of the empirical simulations, which use actual allowance market data as well as two diverse simulations of possible market conditions, demonstrate that under a wide range of circumstances, NPPAFB significantly improves profitability and decreases allowance costs for firms that are required to acquire emissions allowances via open markets.

The primary limitations of the NPPAFB model are that it relies on forecasted future emissions prices and the assumption that a product's demand distribution is known. The two most advanced methods examined in this study (NPPAFB and GOGA) both forward buy emissions using forecasted market prices – therefore substantial forecasting errors should similarly impact both methods. As seen in the results, NPPAFB and GOGA both significantly outperform the other two methods despite the use of a very simple forecasting method; a result that suggests that the benefits of using forecasted emissions prices outweigh the risks of forecasting errors. Likewise, the assumption that demand distributions are known could be flawed if significant market disruptions were to occur. However, it is expected that such market disruptions will have a similar impact on all of the tested methods as all four methods rely on predicted demand distributions to determine each period's production level.

Extensions to this study may enhance the ability of firms to develop effective operating strategies that comply with regulatory requirements. First, as more programs are implemented worldwide, additional data, which can be used to test the robustness of NPPAFB, will become available. Additionally, future research may examine more complex scenarios in which firms weigh the tradeoffs of compliance through investments in emission reducing process improvements versus the costs of advanced allowances acquisition programs.

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