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A Large US Retailer Selects Transportation Carriers Under Diesel Price Uncertainty

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A large US retailer that procures transportation services from third-party carriers experienced an unexpected jump in fuel surcharges as the price of diesel fuel skyrocketed in the summer of 2008. As a result, it sought to limit its future exposure to diesel price risk. We collaborated with this retailer to create a lane assignment optimizer (LAO) that incorporates diesel price risk when selecting carriers for its transportation lanes. The LAO tool has significantly improved the retailer's capability to evaluate the trade-off between the two crucial components of a lane's per-shipment cost: base price and risk-adjusted fuel surcharge. The retailer can now take diesel price risk into account when selecting cost-effective carriers for its lanes, negotiating fuel surcharge limits to share diesel price risk with its carriers, and better aligning the fuel surcharges it pays with the true cost of diesel. We estimate that the more favorable contract terms the retailer negotiated for 2009–2011 translate to nearly $5 million in potential savings during years with unexpected diesel price hikes, such as 2008.

Key words: price uncertainty; risk aversion; service contract; transportation.
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On July 14, 2008, the price of diesel fuel in the United States peaked at $4.76 per gallon, representing a whopping year-over-year increase of 65 percent (U.S. Energy Information Administration 2009c). Consumers, and even more so, businesses with year-long transportation services contracts experienced this price shock at the pump. In particular, a large multibillion dollar US retailer that procures transportation services from third-party full-truckload carriers found itself paying substantially more for freight than expected because of fuel surcharges paid to carriers.

The retailer, like others in its industry, pays carriers diesel price-dependent fuel surcharges in addition to per-truckload base prices; thus, as the price of diesel rose, so did its transportation costs. Most alarmingly, these surcharges sometimes rose faster than fuel prices! The retailer was exceeding its annual transportation budget by millions of dollars and needed to quickly curb its expenses. Fortunately, it was able to renegotiate some of its contracts; however, this required significant effort.

The high diesel prices did not last long: by Christmas, diesel was down to $2.34 per gallon—roughly half what it had been five months earlier (U.S. Energy Information Administration 2009c). Because of its renegotiated contracts, the retailer was out of trouble for the time being. However, it had learned an important lesson: it must explicitly manage diesel price risk. Up to that point, the retailer had been accustomed to evaluating transportation contracts using a rough proxy for expected cost.

In the spring of 2009, the retailer initiated a project with us to improve its processes for (1) selecting transportation carriers, and (2) negotiating better contract terms with these carriers. Together, we developed a linear programming (LP) decision support tool, the lane assignment optimizer (LAO), to help its analysts select transportation carriers under diesel price uncertainty. In addition to base prices, LAO uses carriers' fuel surcharge schedules and analysts' estimates of future diesel prices to select a carrier for each of the retailer's transportation lanes. LAO can incorporate different levels of the retailer's risk aversion and also

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guarantee that the proportion of lanes won by any given carrier falls within a retailer-specified range. We implemented LAO in Excel using Microsoft Solver Foundation to allow the retailer's transportation professionals to easily query it while negotiating with carriers.

By using LAO, the retailer was able to identify and evaluate opportunities to adjust the shape of the fuel surcharge curve it faces. When it renewed its contracts in October 2009, it was able to get all carriers to agree to a common fuel surcharge schedule that has a lower slope (i.e., lower surcharge rate) and a cap (a maximum surcharge rate that applies to all diesel prices above a given threshold). As we will see, changing the slope of the fuel surcharge curve benefits the retailer by aligning surcharges with the true cost of diesel, while capping the surcharge curve allows the retailer to share some diesel price risk with its carriers. Such modifications can be crucial for controlling transportation costs in years when the price of diesel rises dramatically. Had the retailer bent and capped its surcharge curves in this manner in October 2007, we estimate that it could have saved nearly $5 million in 2008.

LAO's specific focus on diesel price risk distinguishes it from other implementations of optimization-based transportation procurement. Although its underlying mathematical program is essentially a general carrier assignment model, as Caplice and Sheffi (2004) describe, specific implementation-based details make LAO useful in practice. In particular, our way of modeling diesel price risk by extrapolating trajectories from a single baseline forecast and then weighting the trajectories according to a risk-aversion parameter contributes to practice because it is (1) fast to calculate, (2) avoids burdensome data requirements like distributions for each period's diesel price or price evolution models, and (3) is intuitive—our risk-aversion parameter is easily tuned because it is not just a nebulous number: its relationship to our model's diesel price trajectories can be seen graphically in LAO's Excel interface.

Our paper also complements existing optimization-based approaches such as those by Powell et al. (1988) and Ergun et al. (2007), which focus on maximizing the profitability of carriers by minimizing the number of empty miles driven between loaded trips. Although we do not explicitly consider the optimization problem of pairing lanes with backhauls, we also care about reducing empty miles; therefore, we discuss how shippers can provide incentives for carriers to solve that problem. From our perspective, fewer empty miles means less diesel used, which lowers diesel price risk.

Finally, our paper contributes to the transportation planning literature by discussing the concept of a fuel surcharge cap and by showing how one retailer successfully implemented fuel surcharge caps to share diesel price risk with its carriers.

We organized this paper as follows. We begin by describing how the retailer purchases transportation contracts and how fuel surcharges are computed in practice. We then describe the retailer's negotiation process prior to our collaboration and the improved negotiation process, which LAO aids. We next describe how LAO computes the risk-adjusted expected cost of each candidate carrier-lane pairing using both these costs and other constraints to find an optimal carrier-lane assignment. We also discuss LAO's easy-to-use Excel interface and its principal benefits. LAO provides an intuitive automated way to compute optimal carrier-lane assignments under diesel price uncertainty and empowers the retailer to negotiate better contractual terms. We conclude with a description of the benefits observed to date.

Background

Fuel Surcharge Basics

The price of diesel fluctuates over time; in some years—notably 2008—this fluctuation was severe (see Figure 1). Because of these fluctuations, carriers typically pass on their diesel price risk by charging a fuel surcharge on top of the agreed-upon per-truckload price. That is, the price carriers charge for a full-truckload shipment is

$$\text{price per shipment} = \text{base price} + \text{fuel surcharge}.$$

The base price stays fixed over the duration of the contract, whereas the fuel surcharge varies according to the price of diesel at the time of shipment. The function that maps the current diesel price to the fuel surcharge levied is called a fuel surcharge schedule.

Fuel surcharges transfer diesel price risk from carriers to shippers (retailers), making it safer for

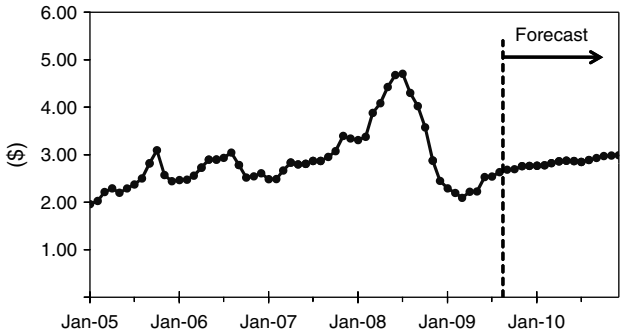

Figure 1: A plot of the US retail diesel price (per gallon) shows the dramatic spike that occurred in the summer of 2008. Although a modest price increase was forecast throughout 2009–2010, there was, of course, a chance that prices could jump back up to 2008 levels (source: U.S. Energy Information Administration 2009a).

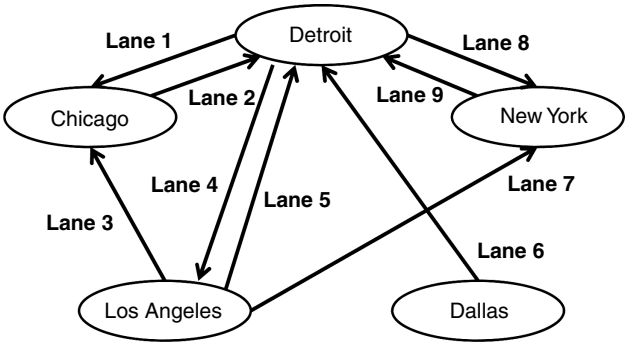

Figure 2: The diagram shows a subset of a retailer's transportation network. Nodes represent cities, and directed arcs represent lanes.

carriers to negotiate long-term high-volume transportation contracts with shippers. If fuel surcharges could be implemented perfectly, the surcharge billed to the shipper would be exactly equal to the carrier's cost of diesel. However, as we will see, fuel surcharges are only rough approximations of the true cost of diesel; typically, they do not account for factors that affect a carrier's fuel economy on specific routes, such as terrain, traffic patterns, speed driven, class of truck, load weight, and proportion of time the carrier's trucks are empty or full. Furthermore, fuel surcharges typically depend on the price of diesel as published in a national or regional price index, whereas carriers buy diesel at times and places other than the index specifies; they might even buy diesel wholesale instead of paying the on-road retail price. Therefore, retailers have latitude to negotiate more favorable fuel surcharge terms with carriers.

Contract Negotiation

Each year, the retailer's contracted carriers accumulate millions of miles moving tens of thousands of truckloads over the retailer's transportation network. This network consists of hundreds of lanes, where each lane is a one-way link between a pair of cities (see Figure 2). Every two years, the retailer negotiates new contracts with carriers to provide service on its transportation network. This negotiation process begins with a request-for-proposal (RFP); the retailer invites 7 to 10 carriers that cover wide geographic areas (e.g., Schneider National, Werner Enterprises, and J. B. Hunt) to submit bids for each lane they would like to operate. The retailer discloses lane volume forecasts; thus, carriers know approximately how many full truckloads they will be asked to transport should they win the contract for a given lane.

With the first round of bids in hand, the retailer would produce a preliminary assignment of carriers to lanes such that each lane was assigned to exactly one carrier—typically, the carrier with the lowest expected cost, computed as the sum of the base price bid and the carrier's fuel surcharge, which is evaluated at the average price of diesel from the previous year. However, because of secondary objectives and side constraints, the retailer would sometimes choose a different carrier to operate a lane. In particular, the retailer ensured that each carrier was allotted at least a few lanes to keep carriers participating in the RFP year after year. The retailer would also limit its dependence on any one carrier by ensuring that it did not assign too many lanes to one carrier; thus, the retailer moderated its supply chain risk and retained its bargaining power for future RFPs. For similar reasons, such market share constraints are typical in other auctions, for example, auctioning school meals in Chile (Epstein et al. 2002).

The retailer would use this preliminary assignment as a starting point for its negotiations with carriers. If an incumbent carrier was reliably running a lane, the retailer typically would prefer to renew the incumbent's contract rather than switching carriers. The retailer might also give that incumbent a chance to match the lowest bid. Similarly, the retailer might ask a carrier that it knows, for example, to be the most

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reliable or the best organized relative to paperwork to match the lowest bid. Several iterations of this manual process, in which carriers would provide the retailer with updated bids, would take place. Once the retailer reached mutual agreements with its carriers for all of its lanes, it would finalize the lane assignment, which would then become contractually binding.

In the negotiation process described above, each bid is for a single lane. However, we should mention that a more sophisticated process for selecting carriers, a combinatorial auction, would allow carriers to bid on a group of lanes with a single package price. Combinatorial auctions can yield more efficient lane assignments because they encourage carriers to offer discounts on bundles of routes; they might reduce their costs, for example, by forming complete circuits in their networks. According to Sheffi (2004), many large retailers use third-party market makers to run combinatorial auctions for them; as a result, they have reduced their transportation costs by 3–15 percent. However, fewer than 10 percent of the lanes won via combinatorial auctions are bid as a group of lanes (Sheffi 2004), indicating that combinatorial auction cost savings result from a few substantial modifications to an otherwise lane-independent bidding process. Because the retailer with which we collaborated does not currently use combinatorial auctions, we will not discuss them in this paper. However, our approach to valuing diesel price risk is also applicable to the combinatorial auction framework.

Fuel Surcharge Details

Each carrier has its preferred way of implementing fuel surcharges; the two most common methods are percentage of base price and surcharge per mile. Of the seven carriers that participated in the retailer's October 2007 RFP, three implemented the percentage-of-base-price method, whereas the other four implemented the surcharge-per-mile method. Carriers that implement percentage of base price define fuel surcharges as a k-percent factor of the lane's base price, where the factor k varies with the price of diesel. For example, given a base price of \$1,000, according to the fuel surcharge schedule in Figure 3, if diesel is

ITEM 201 FUEL SURCHARGE (FSC)

Except as otherwise stipulated, all line haul rates provided in Pricing Agreements and Contract Schedules governed by and subject to this publication will be subject to a Fuel Surcharge (FSC) as provided in the table below. The FSC will apply when the U. S. National Average Fuel Index, as reported by the U. S. Department of Energy, exceeds 109.9 cents per gallon. No FSC will apply when the index is below 110 cents per gallon. The surcharge will be shown as a separate entry on the freight bill and will apply as a percentage of net line haul charges. The FSC will not apply on accessorial charges. The index will be updated every Monday. Revisions to the FSC will go into effect on the following Wednesday. The surcharge amount will be based on the following:

When the index price is at least:	But less than:	Fuel surcharge will be: (%)
110 cents per gallon	115 cents per gallon	0.5
115 cents per gallon	120 cents per gallon	1.0
120 cents per gallon	125 cents per gallon	1.5
125 cents per gallon	130 cents per gallon	2.0
130 cents per gallon	135 cents per gallon	2.5
135 cents per gallon	140 cents per gallon	3.0
140 cents per gallon	145 cents per gallon	3.5
145 cents per gallon	150 cents per gallon	4.0
150 cents per gallon	155 cents per gallon	4.5
155 cents per gallon	160 cents per gallon	5.0
160 cents per gallon	165 cents per gallon	5.5

For each 5 cent increase in the U.S. National Average Fuel Index beyond 165, the FSC will increase 0.5%

Figure 3: An example of a fuel surcharge schedule shows how the fuel surcharge, computed as a percentage of the base price, changes with the price of diesel.

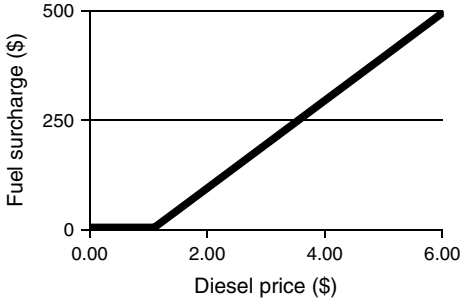

Figure 4: The fuel surcharge schedule from Figure 3 expressed in absolute dollar terms for a lane with a base price of $1,000. The per-truckload fuel surcharge (in dollars) is plotted as a function of diesel price.

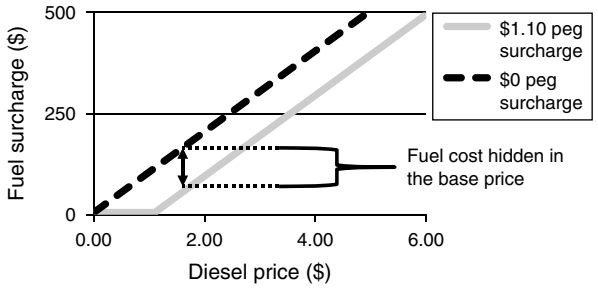

Figure 5: Using the $1.10 peg fuel surcharge schedule from Figure 3 leads to some fuel costs being hidden in the base price, as the graph indicates.

between \$1.55 and \$1.59 per gallon, the fuel surcharge is \$50 (5 percent of \$1,000). However, carriers that implement surcharge per mile define fuel surcharges as being $\$x$ per lane-mile, where x varies with the price of diesel. For example, suppose the surcharge of a carrier is \$0.50 per mile when the price of diesel is \$3.60 per gallon. On a 600-mile lane, this corresponds to a per-shipment fuel surcharge of \$300 ($\$0.50 \times 600$).

The distinction between the percentage-of-base-price and surcharge-per-mile methods can be important, as we will show later. However, for now we note that regardless of how a fuel surcharge is implemented, it can be expressed in absolute dollar terms; that is, the per-shipment fuel surcharge (in dollars) can be expressed as a function of the current diesel price. As Figure 4 shows, fuel surcharge schedules are often piecewise-linear: no surcharges are levied when the price of diesel is below a threshold called the peg (\$1.10 per gallon in this case), and the per-shipment surcharge increases linearly as the price of diesel rises above the peg.

In general, however, fuel surcharge schedules do not need to be piecewise-linear with two segments. Prompted by the run-up in diesel prices in 2008, shippers began experimenting with different fuel surcharge functions; as Bonney (2011) describes, some switched to so-called zero-peg fuel surcharge schedules, which are purely linear and start accruing surcharges on the first cent of diesel paid. As Chris Caplice, executive director of the Center for Transportation and Logistics at the Massachusetts Institute of Technology points out (see Bonney 2011), zero-peg surcharge schedules make fuel surcharges more transparent, making them easier to measure and manage. In general, a fuel surcharge schedule with a $\$k$ peg will begin accruing surcharges when the price of diesel exceeds $\$k$. Thus, the higher the peg, the lower are total fuel surcharges. However, the first $\$k$ of every gallon of diesel the carrier buys is hidden in the base price; therefore, we can expect higher base prices when higher pegs are used (see Figure 5).

The retailer with which we worked has surcharges with pegs in the \$1.10–\$1.30 range. Although this means that some fuel costs are hidden in the base price, this is not a problem for quantifying diesel price risk because the likelihood that the price of diesel will drop below the peg is negligible (i.e., this hidden charge will remain constant in all future scenarios).

The Importance of Explicitly Managing Diesel Price Risk

We define diesel price risk as an unexpected price increase above the level forecast. This is consistent with our claim that fuel surcharges are important in managing diesel price risk, because if carriers could accurately predict all price increases, then the corresponding costs could be built into base prices without a need for fuel surcharges. Along this line of reasoning, we argue that carriers can effectively manage basis risk (i.e., the risk that carriers face because fuel surcharges are computed using a published price index, which might differ from the actual price paid at the pump) by including a risk premium in their base prices. Because basis risk depends on the volatility of the spread (index price minus on-road price) rather than a drastic upward shift in the price

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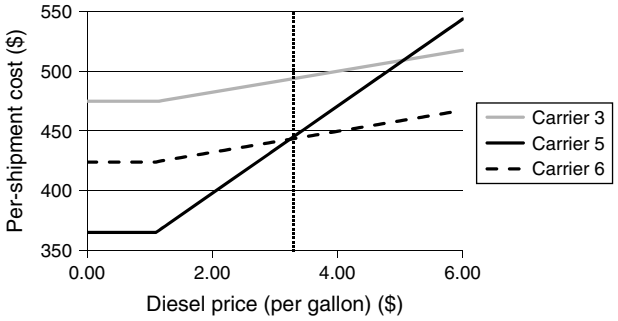

Figure 6: We plot the cost per shipment (base price plus fuel surcharge) as a function of diesel price for three carriers (from the retailer's October 2007 RFP) that offer to operate lane 121. Whether Carrier 5 or Carrier 6 is cheaper depends on whether diesel is above or below $3.30 per gallon.

of diesel, we can view basis risk as a normal cost of doing business; this is not the case for diesel price risk.

It is important for retailers to take diesel price risk into account when choosing which carrier bids to accept, because the carrier that is the cheapest depends on the current diesel price; the cheapest carrier could change as the price changes (see Figure 6). Notice that for lane 121, Carrier 5 is the lowest-cost carrier when diesel is below $3.30 per gallon; however, Carrier 6 is the cheapest when diesel is above $3.30 per gallon. As we will see, the best carrier for a given lane depends on the retailer's diesel price forecast, the uncertainty of this forecast, and the retailer's tolerance for diesel price risk. Often, a risk-averse retailer may be willing to accept a transportation contract with a higher base price if the fuel surcharge schedule has a shallower slope.

The New Contract Negotiation Process

To incorporate fuel surcharges into the retailer's RFP, we initially proposed that each bid for a lane should include both a base price and a lane-specific fuel surcharge schedule. This would entice carriers to modify their fuel surcharge schedules on a lane-by-lane basis to express local comparative advantages in fuel economy driven by, for example, the terrain of the route or the number of empty miles required to pick up a subsequent load. Although the retailer agreed that lane-specific fuel surcharge schedules would be beneficial, it decided, at least for the time being, to limit the number of variables that it negotiates with carriers by instead having each carrier bid a single fuel surcharge schedule to be shared across all of that carrier's lanes.

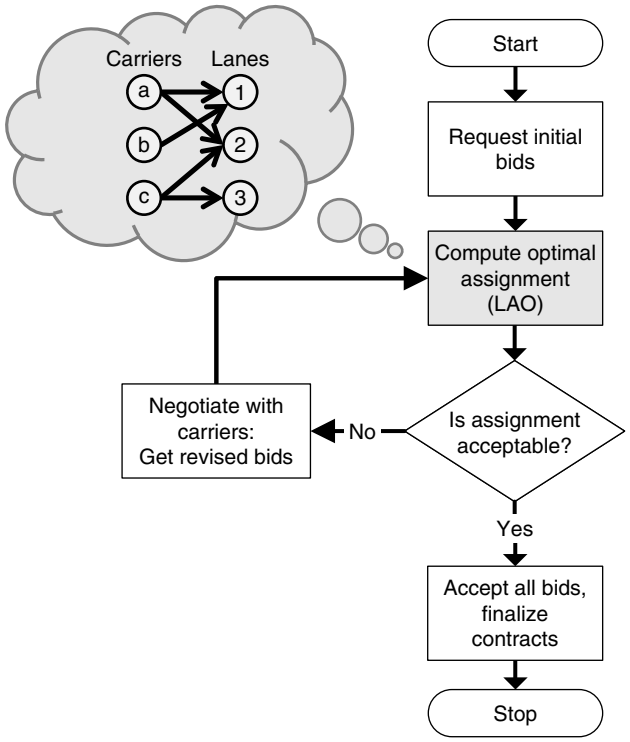

Figure 7: The retailer's transportation professionals can use LAO to compute optimal lane assignments at each iteration of the contract negotiation process.

Given this bidding structure, we used Excel and Microsoft Solver Foundation to develop LAO to compute the cost of each candidate carrier-lane pairing and to subsequently solve for an optimal assignment of carriers (see Figure 7). A crucial component of LAO is how potential diesel price paths and thus diesel price risk are incorporated into the objective function in a computationally cheap, intuitive way. We describe the details of LAO next.

Computing Carrier-Lane Costs

LAO computes the cost of each candidate carrier-lane pairing using formulas that synthesize information from a monthly forecast of diesel prices, a volatility parameter, and a risk-aversion parameter, as well as the base prices and fuel surcharges from the carriers' bids. This section elaborates on these parameters and how they affect cost. To be consistent with the

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retailer's current practice (i.e., its forecasts for diesel prices and lane volumes are available for one year ahead only), we evaluate LAO over a one-year horizon, despite the contracts' durations being two years.

The standard approach to modeling a risk-averse decision maker (Kreps 1988) involves modeling the decision maker's utility function as concave increasing and computing his expected utility over uncertain prices. For example, for expected mean-variance utility, a risk-averse retailer's expected utility for a candidate carrier-lane pairing would be expected annual cost minus some multiple of the variance of annual cost. However, this approach is cumbersome: to compute the variance of annual cost, the retailer would need to estimate the covariance matrix for monthly diesel price—a task it preferred to avoid. Furthermore, the retailer felt that picking a multiplier for scaling the variance in the expected utility calculation was nonintuitive. Thus, in consultation with the retailer, we devised a more intuitive and simpler way of computing risk-adjusted expected costs.

LAO computes the risk-adjusted expected cost of each candidate carrier-lane pairing from a sum of monthly costs. Each monthly cost is the product of an estimated shipping volume times a per-shipment cost. The per-shipment cost is equal to a base price plus a risk-adjusted expected fuel surcharge, which varies by month. Finally, it computes each risk-adjusted expected fuel surcharge by appropriately weighting and summing together the lane's fuel surcharge evaluated along several possible diesel price trajectories. To describe the computation of a risk-adjusted expected fuel surcharge, we must first describe how we generate diesel price trajectories.

Generating Diesel Price Trajectories

The U.S. Energy Information Administration publishes a downloadable report (U.S. Energy Information Administration 2007), which includes a monthly forecast of diesel prices—a monthly diesel price time series that extends one year into the future. We take this forecast as our baseline, which we call the median trajectory or the 50th percentile trajectory. We assume there is an equal chance that the future price of diesel will be above or below this baseline.

To construct additional trajectories, we model the uncertainty of the diesel price at the end of the 12-month horizon. Following the common assumption from the finance literature (cf. Dixit and Pindyck 1994) that price changes are lognormally distributed, we assume that the price of diesel at the end of the horizon is lognormally distributed with median equal to the baseline forecast. The retailer provides as input to LAO the scale parameter of this lognormal random variable (i.e., the volatility parameter); it uses a combination of historical data, market conditions, and its own beliefs about future price uncertainty to estimate the volatility parameter. Different percentiles of this lognormally distributed random variable give different possible end-of-horizon diesel prices. For details, please refer to the appendix.

In addition to the median (50th percentile) trajectory, LAO uses six trajectories, that correspond to price paths that begin at today's price and terminate at the horizon at the 10th, 30th, 70th, 85th, 95th, and 99th percentiles of the lognormally distributed end-of-horizon price. We selected the number of paths and the percentiles of each in consultation with the retailer; more or different levels could easily be accommodated. We interpolate the price points along each trajectory such that no deviation from the baseline occurs today, a 50 percent deviation from the baseline occurs halfway to the horizon, and a 100 percent deviation from the baseline occurs at the horizon (please see the appendix for details). Figure 8 illustrates the seven price trajectories that LAO generates.

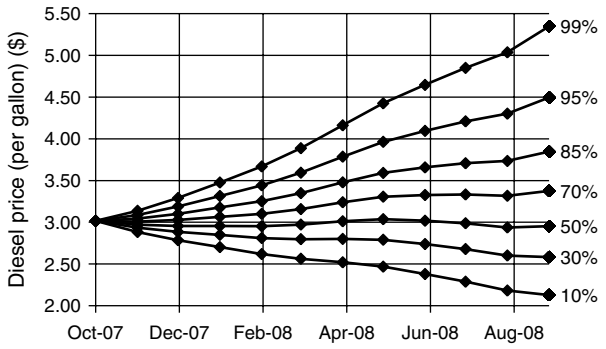

Figure 8: The graph shows an example of the seven price trajectories. Notice that all trajectories mimic the seasonality exhibited in the baseline forecast. We generated these trajectories using a baseline forecast from October 2007, which we used to evaluate LAO over the 2008 run-up in diesel prices.

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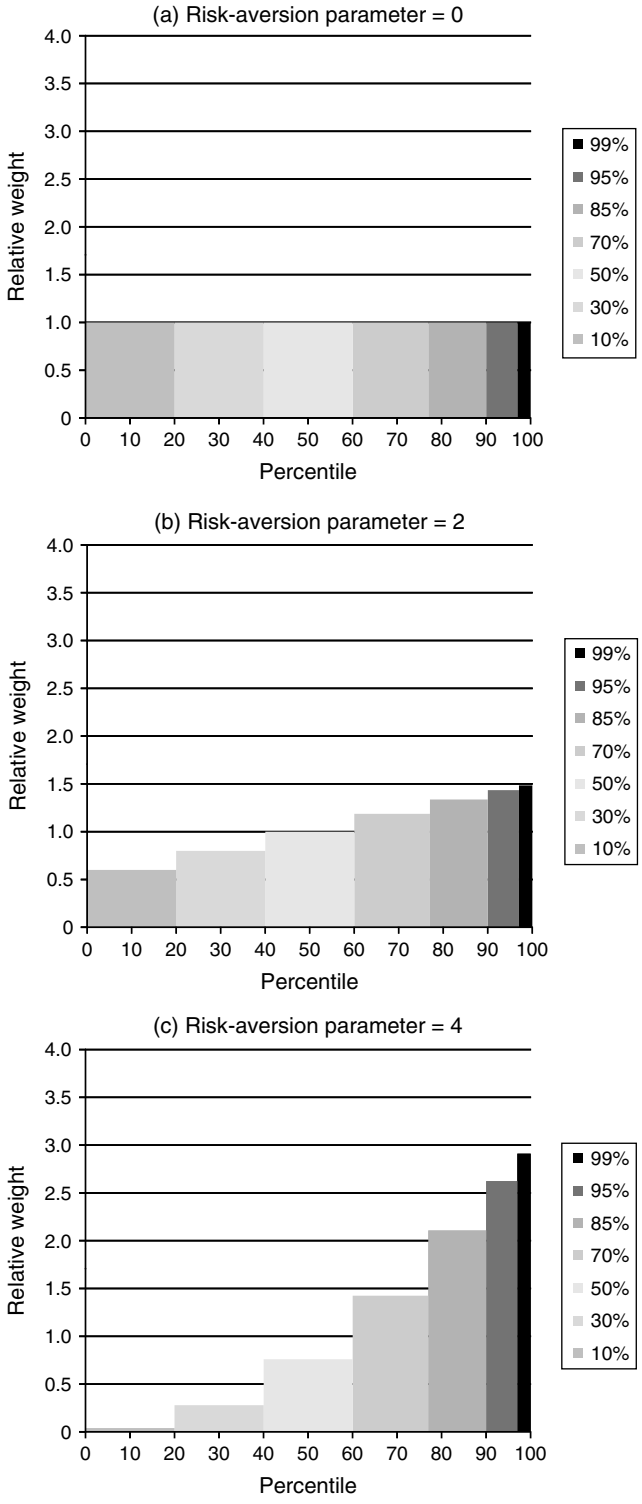

Figure 9: As the risk-aversion parameter increases, LAO gives more weight to higher-percentile trajectories.

Weighting Diesel Price Trajectories

LAO weights and sums the fuel surcharges evaluated along the seven price trajectories to compute a risk-adjusted expected fuel surcharge in each month for each candidate carrier-lane pairing. If a retailer is risk neutral, LAO selects weights so that the risk-adjusted expected fuel surcharges are simply expected fuel surcharges. However, because the retailer tends to be averse to diesel price risk, risk-adjusted expected fuel surcharges are typically higher than expected fuel surcharges.

The retailer's risk-aversion parameter, which LAO uses to skew the weights away from the risk-neutral case, determines exactly how much higher. As the risk-aversion parameter increases, LAO gives more weight to the higher-percentile trajectories, thereby shifting the emphasis of the retailer's plan from using expected diesel prices to using higher-than-expected prices. Therefore, risk aversion is not aversion to price increases from the current price level, but rather aversion to price increases above the projected future price level, as modeled by the forecast (50th percentile trajectory). Figure 9 illustrates how the weights for each trajectory behave as the retailer's risk-aversion level increases. The appendix provides details on how the weights are computed.

Using LAO to Compute Optimal Lane Assignments

We implemented LAO in Microsoft Excel to allow the retailer's transportation professionals to easily interact with it as they negotiate contracts with carriers. LAO contains five main spreadsheets: Settings, Model, SolverResults, Solution, and LaneView.

The user enters the main inputs—a monthly forecast of diesel prices, a volatility parameter, and a risk-aversion parameter—on the Settings sheet, which includes the charts shown in Figures 8 and 9 to guide the user in providing these parameters. In conjunction with lane volumes and the carriers' bids for each lane (input on the Model sheet), Excel formulas use these parameters to calculate the total annual risk-adjusted expected cost for each carrier-lane combination. The computed costs are stored in matrix form on the Model sheet for easy reference.

LAO solves for the optimal carrier-lane assignment using Microsoft Solver Foundation for Excel, which

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pulls data from the relevant spreadsheets and sends the complete solution as output to the Solver Results sheet. Because LAO is intended to be used interactively throughout the negotiation process, it must be fast; it takes less than a second to find the optimal carrier-lane assignment that minimizes risk-adjusted expected costs, subject to lower and upper bounds on the number of lanes each carrier can win. The appendix provides the formal representation of the linear program.

Two spreadsheets summarize the solution: the Solution sheet slices the total annual cost by lane and then by carrier. It also reports the total annual cost of the optimal allocation evaluated along each of the seven diesel price trajectories, thereby providing sensitivity analysis. Base prices and fuel surcharges are separated out for all of the above.

Finally, the Lane View sheet graphically displays, for a single lane, the cost of accepting each carrier's bid as a function of the diesel price (see Figure 6). This interface is particularly useful, because the retailer's transportation professionals can use it to understand how awarding a lane to a carrier other than the one that LAO selected would impact the annual cost of running that lane at various diesel prices.

Implementation

In October 2009, the retailer used LAO in negotiating its new contracts. Its transportation professionals appreciated LAO's user-friendly interface, which helped determine how to (1) bend the cost curve to more closely align surcharge rates with the true cost of diesel, and (2) cap the cost curve to share diesel price risk with the retailer's carriers. We next discuss these two important cost-curve improvements and estimate their cost savings.

Bending the Cost Curve

Carriers use fuel surcharges to transfer the amount they pay for diesel to their customers (i.e., retailers). In practice, this transfer is seldom perfect, leading carriers to either overcharge or undercharge for diesel on a lane-by-lane basis. Graphically, overcharging occurs when the upward-sloping part of the fuel surcharge schedule is too steep. Thus, the retailer would like to identify when a carrier is likely to be overcharging, so it can negotiate to flatten the slope and bend the cost curve (see Figure 10).

Knowing exactly how fuel efficient its carriers are is difficult for the retailer. As we mentioned previously, fuel efficiency depends on many factors, including class and age of truck, driving speed, traffic patterns, flatness of terrain, and load weight. As a starting point, however, the retailer may choose a benchmark fuel economy to compare carriers. For our benchmark, we will use the published national average fuel economy of 6.0 miles per gallon (mpg) for freight trucks, as measured by the U.S. Energy Information Administration (2009b).

We call a fuel surcharge schedule perfectly aligned if the rate at which fuel surcharges are billed to the retailer is equal to the rate at which the carrier spends money on diesel to serve the contracted lane. Thus, a fuel surcharge schedule is perfectly aligned when its slope (as represented in gallons per mile) is equal to the carrier's actual fuel consumption in gallons per mile. A zero-peg perfectly aligned fuel surcharge schedule will ensure that the total fuel surcharges billed in dollars over the life of the transportation contract are equal to the carrier's actual diesel expenditures. Moreover, a $\$x$-peg perfectly aligned fuel surcharge schedule will, if $\$x$ is small enough for the price of diesel to exceed $\$x$ for the entire life

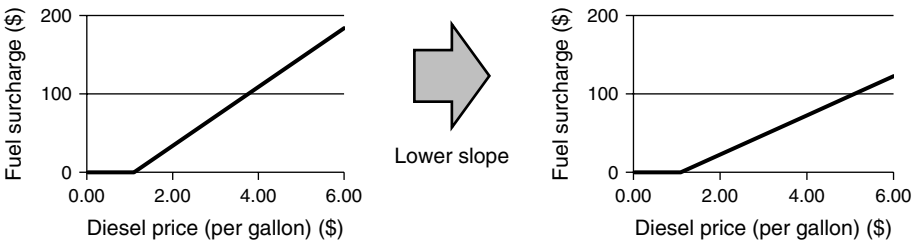

Figure 10: By bending the cost curve, the slope of a fuel surcharge schedule is more closely aligned with the true cost of diesel.

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of the transportation contract, yield a total surcharge in dollars equal to the carrier's actual diesel expenditures, minus the first $\$x$ dollars of each gallon of diesel, which we assume to be included in the lane's base price.

The benchmark 6.0 mpg fuel economy implies a fuel consumption rate of 1/6 gallons per mile, which we can quickly compare with the slopes of the fuel surcharge schedules from the retailer's October 2007 RFP. Doing this, we notice that all carriers that implemented per-mile surcharges charged exactly 20 cents per mile for every dollar that a gallon of diesel was priced above the peg (the peg was carrier specific and in the range of \$1.10–\$1.30). This gives each of these carriers an implied fuel consumption rate (fuel surcharge slope) of 1/5 gallons per mile (\$0.20 per mile ÷ \$1 per gallon), which is 20 percent higher than the 1/6 gallons-per-mile benchmark. Therefore, from this rough analysis, we can conclude that these carriers are overcharging for fuel by about 20 percent (i.e., the retailer has some negotiating room to bend the cost curve).

Of course, this simple analysis does not consider the effect of the empty (deadhead) miles that a carrier must drive to pick up the next load after delivering the retailer's shipment. Because rising diesel prices also increase the carrier's costs of running empty miles and thus decrease the profitability of a given lane, one can argue that a properly aligned fuel surcharge schedule should also transfer the cost of diesel from deadhead miles to the retailer. In this case, a better benchmark for fuel consumption is 0.2033 gallons per mile, which we compute by inflating the old 1/6 gallons-per-mile benchmark by 22 percent because, in 2008, truckload carriers reported they were driving empty 22 percent of the time (American Trucking Association 2008). This benchmark is likely a tad high, because we have not considered that empty trucks weigh less and therefore should have an average fuel economy higher than 6.0 mpg. Nonetheless, we note that when the cost of diesel for running empty miles is included, carriers no longer appear to be overcharging. Thus, a normative question presents itself: Should retailers encourage carriers to use the fuel surcharge or the base price to transfer the cost of diesel used for empty miles back to them?

Lazarus (2010) advises carriers to inflate fuel surcharges to transfer diesel costs for empty miles back to shippers (retailers). Although this approach is prudent for carriers, it may undermine supply chain efficiency. Indeed, if a carrier is bound by a surcharge schedule with a shallower slope than its diesel consumption rate, that carrier will have a strong incentive to lower its fuel consumption to curb its exposure to escalating diesel prices (i.e., carriers will spend more effort finding backhauls to lower the number of empty miles driven, and spend more money upgrading their fleet to boost fuel economy). Therefore, a retailer that is averse to diesel price risk or perhaps one with sustainability initiatives that encourage fuel efficiency may want to accept a higher base price in return for a fuel surcharge schedule with a shallower slope. For this reason, we believe it is appropriate to use 1/6 gallons per mile as a broad fuel consumption target—a fuel consumption rate that will be roughly aligned with the true cost of diesel on lanes with an efficiently chosen carrier.

Figure 11 compares our rough 1/6 gallon-per-mile fuel consumption benchmark with the implied fuel consumption rates offered in the retailer's 2007 RFP. Each point represents the fuel surcharge for a single candidate carrier-lane pair, assuming that diesel is \$4 per gallon. The upward-sloping solid line in Figure 11a, which is our benchmark, represents a carrier with a fuel surcharge schedule with a slope of 1/6 gallons per mile and a peg of \$1.15 (this is appropriate because carriers had pegs in the \$1.10–\$1.30 range). Points below the line are good, whereas points above the line are bad; that is, carrier-lane pairs below (resp. above) the line have shallow (resp. steep) fuel surcharge schedules that pay for fuel at a rate lower (resp. higher) than 1/6 gallons per mile. As we mentioned previously, all carriers with surcharge-per-mile based schedules (indicated by x-marks) have schedules with a 1/5 gallon-per-mile slope; thus, they are above our benchmark.

An interesting pattern surfaces when we look at the carrier-lane pairs from carriers that use percentage-of-base price surcharges (cf. the solid circles in Figure 11). From Figure 11a, we see that the majority of short-haul carrier-lane pairs are above the line and are therefore overcharging for fuel relative to our

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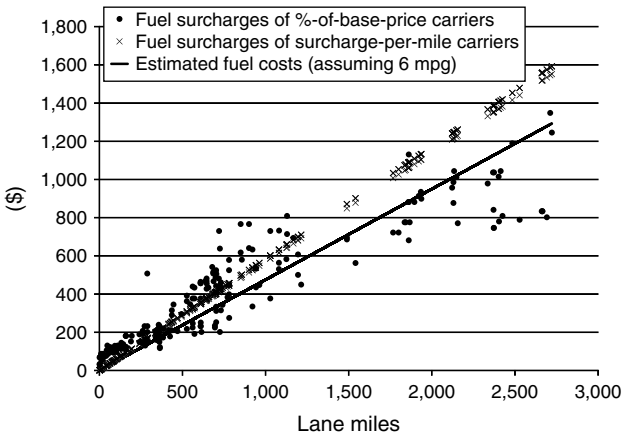
(a) The graph shows the fuel surcharge levied in dollars per truckload for each (carrier, lane) bid, as compared to our benchmark. We assume that the price of diesel is $4 per gallon.



(b) The graph shows the relative amount each (carrier, lane) bid is overcharging for diesel, as compared to our benchmark. The graph does not show 10 outliers (the highest is an estimated overcharge of 12,943 percent on a 1.1 mile lane).

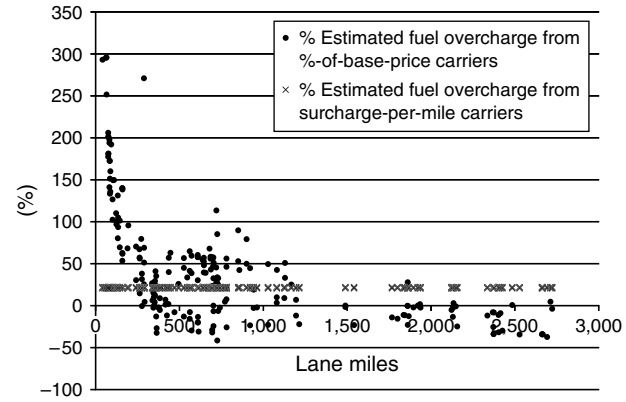


Figure 11: The graphs illustrate fuel surcharges for each carrier-lane pair in the retailer's 2007 RFP, ordered by lane-miles and compared with the 1/6 gallons-per-mile fuel consumption benchmark.

benchmark, whereas the majority of long-haul carrier-lane pairs are below the line and are undercharging. Moreover, Figure 11b shows that the carrier-lane pairs with the lowest lane-miles tend to overcharge the most in percentage terms (computed by taking the gap between fuel surcharge and benchmark from Figure 11a and dividing it by the benchmark). To some extent, we expect this pattern because trucks spend a larger proportion of time in stop-and-go traffic on short-haul lanes than long-haul lanes, which translates into a higher fuel consumption rate for short-haul lanes. However, to a larger extent, this pattern manifests for a different reason.

The overcharging and undercharging pattern of Figure 11b is predominantly a side effect of the retailer's choice to have each percentage-of-base-price carrier adopt a single surcharge schedule for all of its lanes. To see why, note that a carrier incurs both fixed costs and variable costs for transporting a truckload on a lane. The variable costs, which include diesel, increase with the number of lane-miles, but the fixed costs do not. As a result, short hauls have a higher proportion of fixed costs than long hauls, and extremely short hauls ($\sim$1 mile) have almost no variable costs (or diesel costs!) at all. When fuel surcharges are levied directly on lane-miles, short hauls are appropriately surcharged very little. However, when fuel surcharges are levied on base prices, short hauls overcharge because the base price, which includes fixed costs, does not approach zero as lane mileage approaches zero. This effect is strongest for the shortest lanes, as Figure 11b shows, where the estimated percentage overcharge approaches infinity as lane-miles approach zero.

When one surcharge schedule is shared across all of a carrier's lanes, the base price is the only lever the carrier has to express how efficient it would be operating a lane, and because base price includes fixed costs and other nonfuel variable costs, it is difficult for a carrier to use base price alone to show a retailer that a specific lane has a low fuel consumption rate—an important metric for retailers in explicitly managing their diesel price risk. Moreover, because base price is not directly proportional to lane mileage, a retailer cannot use a single percentage-of-base-price schedule to perfectly align fuel surcharges to all of a carrier's lanes. The best we can hope for is that the same carrier wins a good share of both short and long hauls, so that overcharges are roughly balanced by undercharges. In general, this outcome is hard to guarantee without imposing constraints on the distribution of lane lengths assigned to each carrier; however, constraining LAO's assignment problem in this manner would increase the cost of the optimal carrier-lane assignment.

Even in the case in which fuel surcharges are levied per mile, we may benefit from lane-specific surcharges. This is because the specific economics of each

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lane (which depend on the number of empty miles driven to collect the next load) could motivate the use of different fuel surcharge slopes for similar-length lanes that have different backhaul opportunities.

Therefore, we recommend using lane-specific fuel surcharge schedules whenever possible. However, we recognize the necessity to strike a balance between more degrees of freedom with which to optimize and fewer degrees of freedom with which to speed up the RFP's negotiation process. Thus, although the retailer agrees that lane-specific fuel surcharge schedules would be beneficial, and continues to enhance LAO and its negotiation process, the retailer decided to use carrier-specific fuel surcharge schedules in its October 2009 RFP.

Capping the Cost Curve

Typical fuel surcharge schedules (see Figure 4) have unbounded surcharges; that is, if the price of diesel continues to climb, the fuel surcharge assessed to the retailer also continues to increase. As a result, the retailer exclusively bears unlimited diesel price risk. An upper bound to the fuel surcharge schedule, called a surcharge cap, causes diesel price risk to be shared between the retailer and the carrier. With a cap, the carrier bears the most extreme price increases and the retailer bears moderate price increases. Using LAO, the retailer can negotiate to cap the cost curve by establishing a maximum fuel surcharge (see Figure 12).

Certainly, the retailer prefers to lower its exposure to diesel price risk; however, instituting a surcharge cap might be costly because carriers could increase their base prices to compensate for the burden of having a cap. Therefore, the retailer must balance its desire to mitigate diesel price risk with its objective of minimizing the expected cost of transportation; the point at which to strike this balance depends on the retailer's risk-aversion level.

Ultimately, if either party—retailer or carrier—is assigned a higher level of diesel price risk than its comfort level allows, it could engage in hedging by purchasing call options in the diesel futures market. Then, should the price of diesel rise, higher fuel costs would be (partially) offset by revenue generated from exercising the call option. Because diesel is more integral to the carriers' business than to the retailer's, the retailer argued that carriers can leverage their knowledge of diesel prices to potentially hedge diesel price risk at a lower cost than the retailer, motivating the retailer's use of surcharge caps to transfer some diesel price risk onto carriers.

Estimated Cost Savings

In its October 2009 RFP, the retailer began to actively manage diesel price risk by negotiating with its carriers to bend and cap their surcharge schedules. The result of these negotiations was a common fuel surcharge schedule, which all carriers adopted, that significantly reduced the retailer's exposure to diesel price risk. This common surcharge schedule computes surcharges via the percentage-of-base-price method; in comparison to the surcharge schedules from 2007, it has a shallower slope and includes a surcharge cap (a new feature). In response to the lower negotiated fuel surcharges, carriers raised their base prices by 7.26 percent over 2007 levels. However, savings from lower fuel surcharges exceed costs from higher base prices under nearly all diesel price trajectories,

Figure 12: A fuel surcharge cap limits the retailer's exposure to diesel price risk by sharing some risk with its carriers.

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	Without LAO ($)			With LAO ($)		
Trajectory	Base charges	Fuel surcharges	Total cost	Base charges	Fuel surcharges	Total cost
10%	71.9	13.3	85.2	76.9	8.6	85.5
30%	71.9	15.6	87.5	76.9	10.0	86.9
50%	71.9	17.5	89.4	76.9	11.2	88.1
70%	71.9	19.5	91.4	76.9	12.6	89.4
85%	71.9	21.6	93.5	76.9	13.8	90.7
95%	71.9	24.3	96.3	76.9	15.7	92.6
99%	71.9	27.8	99.8	76.9	17.1	94.0
Expected	71.9	17.9	89.8	76.9	11.5	88.4
Actual	71.9	26.3	**98.2**	76.9	16.8	**93.6**

Table 1: We estimate that the retailer could have saved $4.6 million in 2008. All figures are in millions of dollars.

and are most significant for the highest trajectories (i.e., cases with the largest unexpected increase in diesel price).

Table 1 describes two cases: one without LAO and one with LAO. The without-LAO case runs the October 2007 RFP (the last RFP for which we have complete data) according to the retailer's previous evaluation criterion (the cost of a carrier-lane combination is its base price plus the fuel surcharge evaluated at the prior year's average diesel price; i.e., the retailer is risk neutral and expected fuel cost is based on historical data). In comparison, the with-LAO case runs the October 2007 RFP using LAO to optimally select carrier-lane assignments that minimize base price plus risk-adjusted expected cost (with the risk-aversion parameter set at level 4). The with-LAO case additionally uses the common fuel surcharge schedule introduced in October 2009 and raises the base prices of all bids by 7.26 percent. Fuel surcharges were computed from actual 2008 prices (labeled "Actual"), and from forecasted price trajectories (labeled Trajectories 10%, ..., 99%). Expected costs (labeled "Expected") were computed by appropriately weighting and summing the possible price trajectories.

From this comparison, we can see that the with-LAO case has markedly lower costs for high-percentile trajectories, resulting in substantial savings in years in which diesel prices increase dramatically (e.g., 2008). Specifically, evaluating the cost along the actual price trajectory observed in 2008, LAO estimates the retailer could have saved $4.6 million ($98.2 − $93.6) had it used the new fuel schedule with surcharge cap in its 2007 RFP. This analysis serves to illustrate the power of a good decision support tool in helping to negotiate more favorable contract terms.

Conclusions

The LAO tool has improved the retailer's capability to evaluate the trade-off between base price and risk-adjusted fuel surcharge, allowing the retailer to (1) cap and bend its cost curves, and (2) select carriers based on lowest risk-adjusted annual cost. LAO has incorporated diesel price risk into the retailer's carrier selection process, leading to transportation contracts that are robust in the face of uncertain diesel prices.

We note that the retailer decided to convince its carriers to use a common percentage-of-base-price fuel surcharge schedule for all lanes in its October 2009 RFP. In this special case, the common fuel surcharge can be factored out of the objective, leaving LAO to minimize the sum of the base prices from selected carrier-lane pairs. As a result, the optimal carrier-lane allocation under the given common fuel surcharge schedule is independent of diesel price—a strong condition that implies that regardless of how the price of diesel evolves, the retailer will not have an incentive to switch carriers on any lane. However, the retailer pays a price for insisting on this level of homogeneity. As Figure 11 shows, aligning the slope of this common surcharge schedule with all carrier-lane pairs is impossible; thus, short hauls will overcharge. Moreover, by insisting that all carriers adopt the same fuel surcharge schedule, the retailer learns less about individual carriers' fuel consumption rates, making it harder to know which slope and cap to suggest for its common fuel surcharge schedule.

Allowing carriers to competitively bid fuel surcharge schedules on a lane-by-lane basis is the ideal case, because carriers with the best fuel economies would be more apt to win lanes. However, striking a balance between having more degrees of freedom with which to optimize and fewer degrees of freedom to speed up the RFP's negotiation process is necessary. Fortunately, LAO's ability to manage the complexity of lane-specific fuel surcharge schedules will allow the retailer to strategically introduce heterogeneity into its fuel surcharge schedules to capture additional savings in future years.

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α	*lb* (%)	*ub* (%)
10	0	20
30	20	40
50	40	60
70	60	77.5
85	77.5	90
95	90	97
99	97	100

Table 2: Each trajectory α is representative of continuous-space trajectories from the lower-bound percentile (*lb*) to the upper-bound percentile (*ub*).

Appendix

This section provides supplementary material for four sections of the paper: *Generating Diesel Price Trajectories*, *Weighting Diesel Price Trajectories*, *Computing Carrier-Lane Costs*, and *Using LAO to Compute Optimal Lane Assignments*.

Generating Diesel Price Trajectories

Let H be the lognormally distributed end-of-horizon diesel price. Specifically, $H \sim \text{Log-}N(\mu, \sigma^2)$, where e^{μ} is the diesel price specified by the baseline forecast at the end of the horizon and σ is the scale parameter (i.e., volatility parameter) specified by the retailer. Denoting h_α as the α^{th} percentile of H and $\Phi(\cdot)$ as the cumulative distribution function of the standard normal distribution, we have $h_\alpha = e^{\mu+\sigma\Phi^{-1}(\alpha)} = (e^{\mu})(e^{\sigma\Phi^{-1}(\alpha)})$. Thus, we can think of the end-of-horizon price h_α at a given percentile α as the baseline price e^{μ} multiplied by a distortion factor $e^{\sigma\Phi^{-1}(\alpha)}$. To generate the rest of the price points along a trajectory, we progressively attenuate this distortion for price points closer to today's. Thus, for a price point on the αth percentile trajectory at month m of 12, the appropriate distortion factor is $d_{m,\alpha} = e^{(m/12)\sigma\Phi^{-1}(\alpha)}$. Finally, the diesel price in month m along the α^{th} percentile trajectory is $p_{m,\alpha} = p_{m,50} \times d_{m,\alpha}$, where $p_{m,50}$ is the value of the baseline forecast (median trajectory) at month m.

Weighting Diesel Price Trajectories

Let β be the retailer's risk-aversion parameter, which ranges from 0 (risk neutral) to 5 (very risk averse). We treat each trajectory α as a sample path, which occurs with probability w_α. In this section, we describe how the retailer's risk-aversion parameter β determines the weights w_α.

Although we have discretized our sample space to only seven trajectories, we can envision a continuous space of trajectories from the 0th percentile to the 100th percentile (see Table 2).

When $\beta = 0$ (risk-neutral case), we define the weights as $w_\alpha = ub - lb$. However, as β increases, progressively more weight is given to higher-percentile trajectories. The retailer chose the proprietary weighting formulas used for $\beta \geq 1$ to be graphically intuitive. Qualitatively, as β increases, progressively more weight is given to higher-percentile trajectories. Note that the relative weights shown in Figure 9 have been normalized by dividing by the risk-neutral weights $ub - lb$.

Indices

i = a carrier.
j = a lane.
m = a month $\in \{1 \ldots 12\}$.
α = a trajectory $\in \{10, 30, 50, 70, 85, 95, 99\}$.

Decision Variables

$x_{ij} = 1$ if carrier i is assigned to lane j, 0 otherwise.

Parameters

$\underline{a}_i, \bar{a}_i =$ min/max # of lanes to assign to carrier i.
b_{ij} = base price bid by carrier i for lane j.
c_{ij} = annual risk-adjusted expected cost for lane j if carrier i is chosen to operate the lane.
$p_{m,\alpha}$ = diesel price in month m on trajectory α.
r_{ijm} = risk-adjusted fuel surcharge for carrier i, lane j, month m.
$s_{ij}(\cdot)$ = fuel surcharge function bid by carrier i for lane j.
v_{jm} = volume of lane j in month m (# truckloads).
w_α = weight of trajectory α.

Table 3: The table shows the notation used to formally define LAO's inputs and outputs.

Computing Carrier-Lane Costs

Using the notation of Table 3, the risk-adjusted expected fuel surcharge for carrier i on lane j in month m is $r_{ijm} = \sum_\alpha w_\alpha s_{ij}(p_{m,\alpha})$, the price per shipment in month m for carrier i on lane j is $b_{ij} + r_{ijm}$, and the annual risk-adjusted cost of lane j under carrier i is $c_{ij} = \sum_m v_{jm}(b_{ij} + r_{ijm})$.

Using LAO to Compute Optimal Lane Assignments

LAO solves a linear program that minimizes the risk-adjusted expected cost of an assignment, subject to the constraints that each lane is assigned to exactly one carrier, and carrier i is assigned at least $\underline{a}_i$ but no more than $\bar{a}_i$ lanes. This linear program, which always produces integer solutions, is

$$\begin{aligned} \min \quad & \sum_{i,j} c_{ij} x_{ij} \\ \text{s.t.} \quad & \sum_i x_{ij} = 1 \quad \forall j \\ & \underline{a}_i \leq \sum_j x_{ij} \leq \bar{a}_i \quad \forall i \\ & 0 \leq x_{ij} \leq 1 \quad \forall i, j. \end{aligned}$$

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