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Economic impacts of bird damage and management in U.S. sweet cherry production

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ABSTRACT

Bird damage is a common and costly problem for fruit producers, who try to limit damage by using management techniques. This analysis used survey data from producers in five U.S. states to estimate bird damage to sweet cherry (*Prunus avium*) crops with and without the use of bird management. A partial equilibrium model was applied to the data to estimate the change in the marginal cost of production resulting from disuse of bird management. The model incorporates both decreased yield and elimination of management costs. A welfare analysis was conducted with short and long run supply elasticities derived from time-series data using geometric distributed lags. With no bird management, total surplus in the United States decreases by about \$185 to \$238 million in the short run and \$21 to \$29 million in the long run, indicating that bird management has a large impact on cherry production and associated market outcomes, including price and consumption.

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1. Introduction

The United States is the world's second-largest cherry producer after Turkey, accounting for 15% of the world's total output (ERS, 2012a). Cherries are becoming an increasingly important fruit crop. They were ranked the eighth most valuable fruit and nut crop in 2010, generating \$762 million in total cash receipts (ERS, 2012a). Production of sweet cherries (*Prunus avium*) has expanded in recent years, with bearing acreage increasing steadily over the last decade. Expansion of cherry production has been driven by increased consumer demand, due in part to the preventive health attributes of cherries including prevention of cancer, cardiovascular disease, diabetes, and Alzheimer's disease (McCune et al., 2010). Michigan, Oregon, California, and Washington account for about 98% of total U.S. sweet cherry production (ERS, 2012a). Sweet cherries are increasingly utilized fresh (about 75%), and the rest are processed, often as maraschino cherries.

Birds are a significant pest for fruit crops (Dolbeer et al., 1994; Lindell et al., 2012). U.S. apple and grape producers lose tens of millions of dollars each year due to direct bird damage and expenditures on management measures (NASS, 1999; Anderson et al., 2013). Birds reduce crop yields by consuming fruit, damaging fruit which leaves it susceptible to infection, and requiring fruit to be harvested before it is fully ripe, resulting in inferior products (Dellamano, 2006). Almost 60% of sweet cherry growers reported that bird damage is either one of several significant factors affecting their profits, or the most significant factor (Anderson et al., 2013). Since the majority of sweet cherries are sold fresh, even minimal damage can reduce a crop's marketability.

A variety of bird management techniques are available to fruit producers (Conover, 2001; Tracey et al., 2007). Bird-exclusion netting is widely considered one of the most effective methods for reducing bird damage (Dellamano, 2006; Simon, 2008; Anderson et al., 2013). However, installing netting is expensive and labor intensive so many producers avoid using it unless bird damage is severe (Pritts, 2001; Tracey and Saunders, 2003). Application of chemical repellents to crops is another nonlethal method for managing birds. However, development and registration of repellents is costly, so few products are available for agricultural use (Avery, 2003; Eisemann et al., 2011). Methyl anthranilate (MA) is a compound found in Concord grapes that birds perceive as an irritant. Effectiveness of MA as a bird deterrent

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in crops is unproven (e.g. Avery et al., 1996; Dieter et al., 2014). In addition, MA is a volatile compound that must be reapplied frequently, especially after rainfall, making application expensive and time-consuming (Pritts, 2001; Avery, 2003). Other bird deterrent techniques include auditory and visual deterrents and lethal shooting. Many bird management techniques may negatively impact non-target species (Tracey et al., 2007), and the efficacy of some deterrent measures is uncertain.

Limited research has been done on the economic impacts of bird damage to fruit crops, and much of this research has focused on wine grapes (e.g., Crase et al., 1976; Gadd, 1996; Boyce et al., 1999; Berge et al., 2007; and Anderson et al., 2014). A comprehensive study of pest damage on multiple crops was performed by Gebhardt et al. (2011) but the study region only included California, and was not limited to bird damage or cherries. A study focusing specifically on bird damage in cherry production in multiple regions will be useful to producers and policymakers when making decisions about management measures, as well as to researchers developing new technologies for bird management.

Modeling the absence of bird damage management reveals its benefits to growers and consumers. This study analyzes the economic impacts of hypothetical disuse of bird management on sweet cherry production and consumption, and estimates the market outcomes that result from decreased yield and eliminated management costs. It builds on work by Anderson et al. (2013) which used a survey of fruit producers to estimate the costs of bird damage to growers. The survey encompassed five specialty fruit crops across fives states. Direct assessment of bird damage is ideal, but impractical and costly on such a large scale. Under these conditions, producer surveys are the best option for obtaining estimates of crop damage (Conover, 2001). This analysis will elucidate the economic impacts of bird management for both producers and consumers, and may be useful for policymakers when considering future regulations and for producers when making implementation decisions.

2. Methods

2.1. Data collection

A mail survey was distributed to fruit growers in Michigan, New York, Oregon, Washington, and California in the spring of 2012, targeting producers of Honeycrisp apples, blueberries, wine grapes, and sweet and tart cherries (Anderson et al., 2013). The survey consisted of 21 questions soliciting information about acreage, yield, estimates of bird damage, and the bird management techniques used with their associated costs. A total of 7666 surveys were distributed and 2351 completed surveys were returned for a 30.7% response rate.[1] Of those returned 1590 grew one of the crops listed above, and of those, 644 grew sweet cherries.

Producers were asked to estimate their yield loss due to bird damage in 2011, their expected yield loss if they had not used any bird management methods, and their expected yield loss if they and their neighbors had not used any bird management methods. The two differences between yield loss with no management and yield loss with management provide low and high estimates of yield loss for calculating the economic benefits of bird management. Survey data were used in this study for two reasons. First, it is ideal to have data from as many regions as possible, so field studies would have been impractical and cost-prohibitive. Second, bird damage varies from year-to-year, and growers' perceptions are likely based on their experiences over a number of recent years. Their damage estimates are less subject to year-to-year variability than data from a field study. However, there is reasonable concern regarding the reliability of survey data due to possible grower bias or uncertainty. Unfortunately, few previous studies have addressed this topic. A notable exception is Tzilkowski et al. (2002), who compared survey and field study estimates of wildlife damage to corn, and could not conclude that the estimates were significantly different. Other wildlife experts have expressed confidence in growers' ability to assess damage (Conover, 2001). Conversely, growers' ability to assess the impact of their neighbors' bird management practices on their own crops is uncertain, which is why the two damage estimate questions were used as low and high estimates of bird damage to the individual grower's crop.

The price of cherries varies by state and year of production due in part to differences in quality and because different varieties of cherries are better suited for production in different regions. The average price of sweet cherries ranged from \$0.36 per pound in Michigan to \$1.44 per pound in New York from 2009 to 2011 for a nationwide average of \$1.05 per pound (ERS, 2012b).[2] A single price is used for the analysis as varietal differences are considered small enough that all sweet cherries are regarded as a single product.

2.2. Partial equilibrium model

A partial equilibrium model is an economic model in which only one factor is allowed to change while everything else that could potentially affect the market is held constant (Mas-Colell et al., 1995). Prices and quantities produced are allowed to adjust until they are in equilibrium through market interactions between suppliers and consumers. Consumer income and prices of substitutes and complements are assumed not to change. Additionally, changes in a given market are assumed to have no impact on other markets. This type of model makes analysis of the effects of single changes much simpler.

A partial equilibrium model developed by Anderson et al. (2014), in which producers explicitly choose to employ bird management, was applied using the survey data. The model is similar to the models developed by Lichtenberg et al. (1988) and Sunding (1996) in that all have the same data requirements and can be used to estimate welfare changes. Supply and demand elasticities, market price, production data, and cost-effectiveness of bird management are necessary to apply the model.[3] Farm-level demand for cherries has been reported as inelastic (Schotzko et al., 1989; Cembali et al., 2003), and an average of reported estimates was used for this analysis. Estimates of management costs and crop damage were obtained from the survey results, and supply elasticities are derived in the following section.

Each producer's profit maximization problem is described by.

$$\max\pi = Pq(X, Z) - xX - zZ, \tag{1}$$

where X is the number of acres harvested in a given year, Z is the number of acres to which bird management is applied, x is the per-acre production cost excluding the cost of bird management, z is the per-acre cost of bird management, and P and q are market price and quantity produced. First order conditions are $\frac{\partial\pi}{\partial X} = P\frac{\partial q}{\partial X} - x = 0$ and $\frac{\partial\pi}{\partial Z} = P\frac{\partial q}{\partial Z} - z = 0$, implying that producers will use bird management on an acre if the additional revenue gained from doing so is greater than the cost. Input demand functions are $X^* = X(P, x, z)$

[1] Response rate was calculated by dividing the number of returned surveys by the number of distributed surveys.

[2] Prices were adjusted to 2011 dollars.

[3] Perfect competition, identical producers, and product homogeneity are assumed for this model.

and $Z^* = Z(P, x, z)$, where X^* and Z^* are the optimal quantities of acres harvested and bird management given current regulations.

Assuming linearity, the current market supply function is

$$Q_S^* = Q_S(X^*, Z^*) = Q_S(P, x, z) = a + bP, \tag{2}$$

where a and b are functions of x and z and $b = \frac{E_S Q}{P}$. Demand is $Q_D = \delta + \gamma P$, where $\gamma = \frac{E_D Q}{P}$. Equilibrium is described by $Q_S = Q_D$ and $P = MC$.

Total disuse of bird management would restrict Z to zero and change the producers' marginal cost function from $MC = \frac{Q-a}{b}$ to $MC_2 = \frac{-a}{b} + k + \frac{Q}{b(1+L)}$, where $k = \frac{\Delta z}{yield\ per\ acre}$ and $L = \frac{\Delta\ yield\ per\ acre}{yield\ per\ acre}$. The change in marginal cost is given by:

$$\Delta MC = k - \frac{QL}{b(1+L)}. \tag{3}$$

Management cost per unit produced is represented by k and is constant across all output. Elimination of all bird management would make the numerator of k the negative of what is currently being spent per acre on bird management. L is the percent reduction in yield due to elimination of bird management, and causes the change in marginal cost to increase as production increases, and decrease as production decreases. The new marginal cost (MC_2) is obtained by adding k to the original marginal cost equation and solving for q, then multiplying by $(1 + L)$ and solving for MC. Subtracting MC from MC_2 gives the change in marginal cost. The two terms in this equation reflect the two opposing shifts of the supply curve (Fig. 1), the first being the removal of management costs reflected as a parallel shift to the right to S', and the second the decrease in production resulting from bird damage reflected as a leftward pivot to S_2.

The change in bird management results in a new supply function given by $Q_S = \alpha + \beta P$, where $\alpha = (1 + L)(a - kb)$, and $\beta = (1 + L)b$, and the new equilibrium price is $P_2 = \frac{\delta - \alpha}{\beta - \gamma} = \frac{\delta - a - aL + kb + kbL}{b + bL - \gamma}$. The market-wide changes in consumer and producer surplus are given by $\Delta CS = \int_{P_2}^{P_1}(\delta + \gamma P)dP$ and $\Delta PS = \int_{-\alpha/\beta}^{P_2}(\alpha + \beta P)dP - \int_{-a/b}^{P_1}(a + bP)dP$.

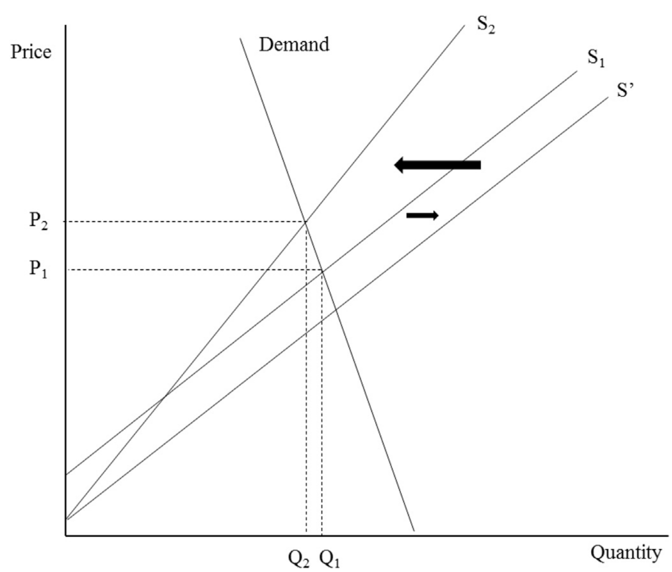

Fig. 1. Shifts of the supply curve in response to changes in bird management. S_1 = supply curve with bird management, S' = intermediate supply curve, S_2 = supply curve without bird management, P_1 and Q_1 = price and quantity with bird management, P_2 and Q_2 = price and quantity without bird management.

2.3. Derivation of supply elasticities

A range of supply elasticities was estimated for this study for two reasons. First, an estimate of the price elasticity of supply for cherries could not be found in the published literature. Studies that include cherry production generally use the elasticity of another fruit crop (Cembali et al., 2003). Since this study is focused solely on cherries, a cherry-specific supply elasticity was deemed appropriate. Second, supply elasticities for crops are known to change over time, increasing from the short run to the long run (Hoddle et al., 2003). Therefore, a single value would not capture the change in welfare given various time frames. Short run elasticities apply to the present or very near future in which certain aspects of production cannot be easily adjusted (e.g. orchard size). Long run elasticities are used to describe time frames that extend further into the future, in which growers have more flexibility to adjust production inputs (Nicholson and Snyder, 2011). A set of elasticities ranging from short run to long run provides a more realistic framework in which growers make production decisions.

In a competitive market, producers choose the quantity of a good they will supply based on the market price of that good. Cherry growers cannot easily respond to price changes in the current year because trees require several years to mature. Instead, they look back at prices from previous years to predict what future prices might be and use this information to determine what their long-term investment in orchards should be. These expectations are likely formulated using information from several past years and can be measured using distributed lags. A model using geometric distributed lags as described by Ferris (2005) was applied to thirty years of price and production data[4] (ERS, 2010). The model uses a supply equation in which the quantity produced in a given year t is a function of past prices, which are given decreasing importance as they become more remote: $Q_t = \alpha + \sum_{i=1}^{\infty}\beta_t P_{t-i}$ where $\beta_i = \beta\lambda^i;\ 0 < \lambda < 1;\ i = 1, 2\ldots\infty$. The equation is manipulated to derive the ordinary least squares (OLS) regression equation $Q_t = (1 - \lambda)\alpha + \lambda Q_{t-1} + \beta\lambda P_{t-1}$. The terms $1-\lambda$, λ, and $\beta\lambda$ are the OLS coefficients, and are used to calculate a series of supply elasticities ranging from short run to long run time frames. The supply elasticity in the initial time frame that bird management is unavailable is assumed to be zero, since producers have no opportunity to adjust production inputs.

2.4. Welfare analysis

The welfare analysis described here measures the impacts of bird damage and management to both cherry producers and consumers by calculating changes in surplus. Producer surplus measures the additional value producers gain by selling their product at a price above the minimum price they require. Similarly, consumer surplus is the extra value consumers gain by paying less than they are willing to pay. Total (social) surplus is the sum of producer and consumer surplus. Decreased yield causes an increase in cost of production resulting in higher prices, and the welfare of both consumers and producers is affected.

Changes in producer and consumer surplus due to total disuse of bird management methods were calculated using high and low estimates of yield loss provided by producers. The change in marginal cost was calculated using information about the cost of bird

[4] The model uses thirty years of data to estimate supply elasticities. This should not be confused with the length of time producers use to make predictions about price, which is probably only a few years.

Table 1
Demographic information of survey respondents by state.

	Total number of sweet cherry farms[a]	Number of survey respondents[b]	Proportion of farms responding	Average yield per acre (tons)	Average acreage	Average annual bird management costs
California	1226	131	11%	4.81	66	$2328
Michigan	639	150	23%	3.98	25	$380
New York	304	88	29%	3.40	5	$692
Oregon	777	107	14%	5.11	62	$1069
Washington	1958	162	8%	6.73	35	$2056

[a] NASS 2012, www.nass.usda.gov/Statistics_by_State.
[b] Four respondents did not list their state, one listed OH, and one listed WI. These are not included in this table.

management techniques and the additional damage producers expected to see in their crops if no bird management was used. Surplus changes were calculated for each time frame using a constant demand function. A new supply function was derived from the original for each time frame (elasticity) for both high and low estimates of a change in bird management. Surpluses were calculated for each supply function and compared with the original to determine the effect of reduced bird management. Supply functions were assumed to be perfectly inelastic in the first period that bird management is not used, meaning that the change in producer surplus is equal to the change in total revenue during that period.

3. Results and discussion

3.1. Survey results

Among sweet cherry growers, the average farm grew 39 acres of sweet cherries yielding five tons per acre (Table 1), and growers had an average of 33 years of farming experience. Sweet cherry growers reported American robins (*Turdus migratorius*) and European starlings (*Sturnus vulgaris*) as the most damaging bird species. Growers also reported which bird management methods they used (Fig. 2), and how effective the believed those methods were (Fig. 3). Note that exclusion netting was the least-used management method, although it was reported as the most effective. This is probably due to the high costs of installation and maintenance.

Producers estimated their average yield loss due to bird damage was 13% in 2011 (Table 2). They estimated that their own use of bird management reduced yield loss by 21% and disuse of bird management was predicted to increase yield loss by about 26%. These results indicate that current bird damage mitigation techniques are highly, but not completely, effective. The estimates were entered into the partial equilibrium model as low and high estimates of the reduction in yield resulting from reduced bird management.

The estimated yield lost under total disuse of bird management was not much larger than the expected loss when the producer alone stopped using bird management. This could indicate that producers expect management methods used by others will have a small effect on their own production, or that producers have limited information about the effectiveness of their neighbors' management efforts. Additionally, a spillover effect may occur when nearby operations use nonlethal bird management techniques. Birds deterred from one farm may simply go to a neighboring farm, increasing the density of birds on those farms. In this case, when a producer's neighbors stop using bird management the producer may actually experience a decrease in bird damage. Although information about neighbors' production practices would have been useful for this study, this information was not solicited due to privacy concerns.

3.2. Supply elasticities

Coefficients in the supply elasticity model were significant at the one percent level, indicating that growers are influenced by past prices when deciding how much to produce (Table 3). The model produced a series of supply elasticities over twelve time frames, converging in a long run elasticity of 3.14 (Table 4). These elasticities suggest that supply is inelastic in the shortest time frame and becomes elastic in longer time frames. Each time frame represents one growing season.

3.3. Welfare analysis

Demand is inelastic, so the changes in producer surplus are positive and the changes in consumer surplus are negative in each time frame. As the supply elasticity converges to the long run elasticity, the changes in producer and consumer surplus between the original situation with bird management and the new situation

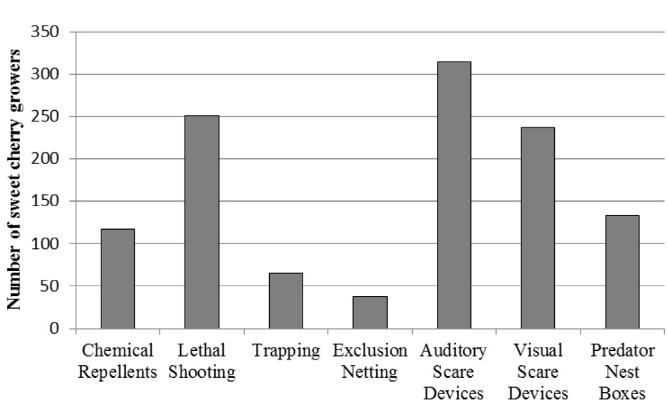

Fig. 2. Bird management methods used by sweet cherry growers.

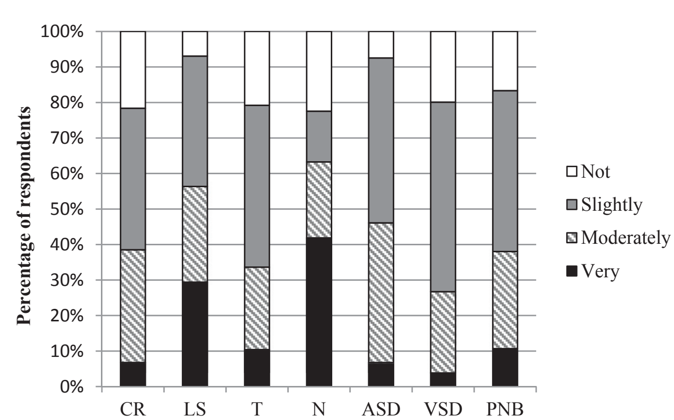

Fig. 3. Effectiveness of bird management methods according to sweet cherry growers. CR = chemical repellents, LS = lethal shooting, T = trapping, N = exclusion netting, ASD = auditory scare devices, VSD = visual scare devices, PNB = predator nest boxes.

Table 2
Growers' estimates of yield loss from bird damage (standard deviation) and cost of managing bird damage.

Average percent yield lost to bird damage	Average percent yield lost with no management by:		Percent change in yield without bird management (L)		Average cost/acre of bird management (z)
	Producer	Producer + neighbors	Producer	Producer + neighbors	
12.72 (18.87)	31.09 (29.30)	35.32 (30.47)	−21.05	−25.89	$127.71

Table 3
Regression results for derivation of supply elasticities.

	Coefficients	Standard error	t-stat	p-value
Intercept	−127404.12	37692.78	−3.38	0.002297
Qt-1	0.53	0.13	4.22	0.000263
Pt-1	138.43	23.42	5.91	3.10E-06

Table 4
Supply elasticities.

Time frame	Elasticity
t+1	0.72
t+2	1.45
t+3	2.06
t+4	2.50
t+5	2.78
t+6	2.94
t+7	3.03
t+8	3.08
t+9	3.11
t+10	3.13
t+11	3.13
t+12	3.14

without bird management decrease. This is due to the decreasing differences between supply elasticities as the time frame increases, and the accompanying smaller decreases in price and quantity changes.

The decrease in total surplus ranged from $185 million to $238 million in the short run and $21 million to $29 million in the long run (Table 5). Producer surplus increases without bird management because the demand curve is inelastic at the original equilibrium point (although not necessarily at the new equilibrium points), so the increase in price is proportionately greater than the decrease in production. This means that producers would actually benefit from total elimination of bird management. However, this is only true when all producers are not using bird management. If a few growers are using bird management, their lower costs will allow them to sell at lower prices, and the competitive nature of the market will incentivize other growers to find some way to lower their own costs (likely by adopting bird management practices themselves) so they can compete. Without bird management, the change in consumer surplus decreases over time frames as price and quantity converge on the new equilibrium point.

4. Conclusions

Birds are a known cause of crop damage and loss. Sweet cherry producers often resort to using multiple bird management methods, increasing their costs while still losing about 13% of their crop to birds. However, without any bird management producers estimate that the amount of their crop lost to birds would increase substantially.

Overall, the total cost of complete disuse of bird management to society would be between $185 and $238 million immediately, and $21 to $29 million in the long run. Conversely, bird management in cherry production can be said to benefit the U.S. by these amounts. Since producers continue to lose a significant portion of their crop to birds with current management techniques, benefits to consumers could be increased with improved methods for management. Producer surplus may decrease, but this analysis demonstrates that consumer benefits of bird management are greater than producer losses, suggesting that total surplus could be increased with lower yield losses.

The findings of this study may be used to inform decisions regarding bird management policy by providing policymakers with information about the value of current bird management and the possible benefits of improved methods. This information could also be used when estimating the rate of return of new research for bird management. Policymakers, producers, researchers, and the public can benefit from accurate information about the value of bird

Table 5
Changes in market outcomes for sweet cherries after a reduction in bird management.

$E_D = -0.47$	Low estimate of yield loss					High estimate of yield loss				
E_S	ΔP[a]	ΔQ_D[b]	ΔCS	ΔPS	ΔTS	ΔP[a]	ΔQ_D[b]	ΔCS	ΔPS	ΔTS
0.00	0.47	−143.64	−288.40	102.98	−185.42	0.58	−176.67	−345.12	107.47	−237.65
0.72	0.21	−62.72	−134.28	28.34	−105.94	0.26	−80.50	−169.99	32.98	−137.01
1.45	0.13	−38.88	−84.77	31.36	−53.40	0.17	−50.89	−109.93	38.61	−71.32
2.06	0.10	−28.98	−63.65	28.15	−35.50	0.13	−38.41	−83.76	35.21	−48.55
2.50	0.08	−24.31	−53.57	25.63	−27.94	0.11	−32.47	−71.13	32.25	−38.88
2.78	0.07	−21.96	−48.49	24.16	−24.33	0.10	−29.49	−64.75	30.48	−34.26
2.94	0.07	−20.75	−45.86	23.34	−22.52	0.09	−27.95	−61.44	29.50	−31.94
3.03	0.07	−20.12	−44.49	22.90	−21.59	0.09	−27.14	−59.70	28.97	−30.73
3.08	0.07	−19.79	−43.76	22.67	−21.09	0.09	−26.72	−58.78	28.68	−30.10
3.11	0.06	−19.61	−43.38	22.54	−20.84	0.09	−26.49	−58.30	28.53	−29.77
3.13	0.06	−19.52	−43.17	22.47	−20.70	0.09	−26.37	−58.04	28.44	−29.59
3.13	0.06	−19.47	−43.06	22.44	−20.63	0.09	−26.31	−57.90	28.40	−29.50
3.14	0.06	−19.44	−43.01	22.42	−20.59	0.09	−26.28	−57.83	28.38	−29.45

[a] Price in dollars/pound.
[b] Quantity in million pounds.

management.

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