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A Market Basket Analysis of Beef Calf Management Practice Adoption

Brian P. Mulenga, Kellie Curry Raper, and Derrell S. Peel

Existing studies on calf management practice adoption tend to treat practices individually and, by implication, ignore the possibility that some practices are more likely to be jointly adopted than others. This study applies market basket analysis, commonly used in retail marketing for prediction of consumer purchases, to examine bundling of calf management practices based on the likelihood of joint adoption using producer survey data. Results indicate that the base practices of horn management, deworming, and castration are the three most widely adopted practices and are more likely to be jointly adopted in varying combinations with other practices. Producers who adopt feed bunk training jointly with base practices are less likely to implement 45-day weaning, but those who do implement 45-day weaning are more likely to adopt feed bunk training. Based on conditional probabilities, respiratory vaccinations appear to be the last piece of the puzzle for completing the preconditioning bundle. Results indicate that likelihood of implant adoption is highest when all preconditioning practices have already been adopted. We discuss implications on extension programming and future studies concerned with understanding practice adoption decisions.

Key words: value-added, conditional probabilities, cow-calf, association rule

Introduction

Basic value-added beef production and management practices by cow-calf producers such as castration, dehorning, vaccination and longer pre-marketing weaning periods help improve animal health, meat quality, and weight gain in later stages of production (Williams et al. 2013; Schumacher, Schroeder and Tonsor 2012). For stocker producers and cattle feeders, improved feeder calf health implies lower medical treatment costs and enhanced weight gain as calves move through the supply chain, ultimately reducing production costs. Thus cattle buyers have an incentive to pay a premium for preconditioned calves. Multiple empirical studies indicate that value-added beef management practices attract price premiums and could improve producer profits. Williams et al. (2012) found discounts of $5.77/cwt for uncastrated male calves and premiums of $15.54/cwt for certified VAC-45 program calves.[1] Dhuyvetter, Bryant and Blasi (2005) found positive returns for calves in a 45 day weaning program. A study by Behrends, Field

Brian P. Mulenga is a graduate research assistant, Kellie Curry Raper is an associate professor, and Derrell S. Peel holds the Charles Breedlove Professorship in Agribusiness in the Department of Agricultural Economics at Oklahoma State University.
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[1] Certified VAC-45 preconditioning programs represent a bundle of health management practices which typically include castration, horn management, deworming, two rounds of respiratory vaccinations, feed bunk training and a minimum of 45 days weaned prior to marketing. Some programs may include additional requirements.

and Conway (2001) found that feedlot managers indicated positive willingness to pay premiums for numerous individual value-added practices that impact longer-term animal health.

Despite documented benefits and premiums associated with many health management practices, producers often choose not to implement them (Schumacher, Raper, and Peel 2017). This disconnect between the expected benefits of adoption and often lower than expected adoption rates has given rise to a number of studies aimed at better understanding producer behavior regarding practice adoption (e.g., Schumacher, Raper, and Peel 2017; Williams et al. 2013; Pruitt et al. 2012). Existing studies on management practice adoption tend to treat practices individually and by implication ignore the possibility that some practices are more likely to be jointly adopted, such as castration and dehorning. For example, Williams et al. (2013) model the determinants of the number of practices adopted using a negative binomial model but do not consider joint adoption of specific practices. Popp, Faminow and Parsch (1999) and Ward et al. (2008) use logit models to explain determinants of adoption for individual practices. Ward et al. (2008) disaggregate producers by scale of operation and level of dependence on cattle income, but still treat practices individually.

Some practices may typically be adopted jointly; hence, adoption decisions across such practices will be correlated. Beef Quality Assurance guidelines recommend both castration and dehorning for calves at or before three months of age, as both practices induce less stress at younger ages (BQA 2019). A producer who is already rounding up calves to implement one of those practices may be more likely to implement the other while the animal is in the chute. Though the prevalence of implanting calves has decreased, implants can be given to calves as young as 45 days old. Some producers may implement castration, dehorning and implants in one trip through the chute, benefiting from time and labor savings by minimizing the number of times that calves are physically handled prior to marketing. Vaccinations are generally recommended in two rounds approximately three weeks apart prior to weaning and at weaning, with an average weaning age of approximately 7 months. Some producers may choose to castrate and dehorn calves at a later age and give first round vaccinations at that time. The timing and combinations of practice implementation can vary across operations, but there are likely some practices that tend to be implemented together. Knowledge of typical practice bundles along with probabilities that other individual practices might be added to an existing bundle can help educators begin to examine how extension programming related to calf health management practice adoption might be more effective. Treating adoption of individual practices as independent decisions leads to loss of information because correlation information is implicitly disregarded.

This study examines correlation among practices by clustering practices based on the likelihood of joint adoption. Using data from a 2018 survey of Oklahoma cow-calf producers, we implement market basket analysis to address two objectives: 1) to identify and construct bundles of practices likely to be jointly adopted together, including a measure of the associated probabilities; and 2) to estimate the probability of adopting an individual practice conditional on adoption of a specific practice bundle. The market basket analysis approach typically parses data down to "what is in the basket" (the Amazon approach). The analysis looks strictly at purchase connections between products – or in this case, adoption connections between practices – with no demographic information attached. Analyzing practice adoption in this way highlights producer bundling choices and projects likely adoption progression paths, facilitating more critical thinking about the process before other information is considered.

Methods

At the core of this study is the need to identify practices that producers are more likely to adopt as a bundle. Toward that end, we borrow from the retail marketing literature and apply the association rule learning technique suggested by Hahsler, Grün and Hornik (2005) described as market basket analysis. Market basket analysis is used in retail marketing to identify groups of items that customers tend to purchase together and to calculate the associated probability of purchasing that item set (Linoff and Berry 2011; Shaw et al. 2001; Agrawal, Road and Jose 1993). Market basket analysis also identifies additional items likely to be purchased by the customer conditional on the current items in their market basket and the associated conditional probability. The probabilities are described as statistical affinity calculations that can help retailers better understand and serve customers, based on revealed and predicted behavior. Amazon, for example, uses market basket analysis to determine their "Frequently Bought Together" and "Customers Who Bought This Also Bought This" recommendations that appear when customers are shopping. The same methodology can be applied to producer behavior in the context of practice adoption. Using the context of market basket analysis, we can identify practices that producers are likely to implement as bundles, establish the probability of that bundle's occurrence, and calculate the statistical affinity, i.e. the conditional probability, of the producer also choosing to implement another specific practice, given that bundle. In retail, market basket analysis can help businesses understand customer behavior. In our setting, statistical affinity calculations can help us better understand producer practice adoption behavior, ultimately informing the way that we serve producers through educational programming related to practice adoption.

In this study, we define individual items as the practices adopted by a producer. Similar to the item set, we define practice bundles as practices more likely to be jointly adopted by a producer. The practice bundle (item set) is referred to as the antecedent and the additional practice that may be adopted conditional on adoption of the practice bundle is referred to as a consequent. Following Agrawal et al.'s (1993) original formulation of the association rule, let $I = \{i_1, i_2, i_3 \ldots, i_7\}$ be a set of 7 practices a producer is encouraged to adopt. Each practice is represented as a binary variable where 1 represents adoption and 0 represents non-adoption. Further, let T be the number of observations where producers adopted at least one of the 7 practices. Each observation of the sample (T) comprises all or a subset of practices in I. Each entity in T thus contains a bundle of practices whose size can range from 1-7.

The association rule is defined as $X \Longrightarrow Y$, where $X \subset I$, $Y \subset I$, and $X \cap Y = 0$. With this formulation, it is possible to identify, with a certain probability, a practice bundle, X, most likely to be adopted by a producer, and practice Y likely to be adopted conditional on adopting bundle X. Each rule contains two different practice bundles, X and Y, where X is referred to as the antecedent or left-hand side (LHS) and Y is the consequent or right-hand side (RHS). Following Hahsler et al. (2005), the important parameters to consider in evaluating the precision of discovered association rules are support, confidence, and lift. Support measures the frequency with which an item set, or practice bundle in this case, appears with one other practice in the dataset. Support is thus defined as proportion of observations out of total observations T, which contains the practice bundle X and one other practice Y. Practice bundles that are more frequent in the data will have higher support than those less frequently adopted. Mathematically, support can be expressed by the equation

$$\text{(4.1)} \qquad support\ (X \cup Y) = \frac{Frequency\ (X \cup Y)}{T}$$

We can also define support for bundle X as $support(X) = \frac{Frequency\ (X)}{T}$ and support for bundle Y as $support(Y) = \frac{Frequency(Y)}{T}$.

Setting a minimum support threshold aids in identifying practice bundles that occur frequently enough in the data to warrant further examination. Bundles with support below the chosen minimum threshold are considered not to contain enough information to infer meaningful conclusions from that particular rule. Confidence is a measure of how often a rule holds. Specifically, it measures the percentage of observations in which Y has been adopted given that bundle X is already adopted, i.e. the conditional probability of Y given X (e.g., see Hipp, Güntzer and Nakhaeizadeh 2007). Mathematically, confidence can be expressed as:

$$\text{(4.2)} \qquad confidence\ (X \Longrightarrow Y) = \frac{Frequency\ (X \cup Y)}{Frequency\ (X)}$$

In order to draw meaningful conclusions from associations, association rules must meet both a minimum support level (*minsup*) and a minimum confidence level (*minconf*) simultaneously. Low to medium support values often result in a larger number of frequent item sets, making it difficult to identify useful association rules. Setting minimum threshold values is at the discretion of the user and may differ across applications. A measure known as the lift can be used to further filter or rank discovered rules (Brin et al. 1997). Lift is defined as the ratio of the observed support of *X* and *Y* to that expected if *X* and *Y* were independent. Lift can be mathematically represented as:

$$lift(X \Rightarrow Y) = \frac{support(X \cup Y)}{support(X)\, support(Y)} \tag{4.3}$$

With this ratio in mind, lift values greater than 1 imply that observed support of *X* and *Y* is larger than if the two were independent. Therefore, in terms of association strength, lift values greater than 1 indicate stronger associations (Hahsler et al. 2005).

To avoid an exploding number of candidate bundles and to minimize the risk of discovering spurious associations, we apply the Apriori algorithm as suggested by Agrawal and Srikant (1994) and Yabing (2013). Generally, the Apriori algorithm identifies the frequent individual items in the dataset, i.e. individual items that meet both the *minsup* and *minconf.* These are then expanded to larger item sets (bundles) by sequentially adding more items (practices) and only keeping bundles that meet the *minsup* and *minconf*. Any subset bundles that do not meet the *minsup* and *minconf* are filtered out and those meeting the *minsup* and *minconf* are integrated in the appropriate frequent bundles. The frequent item sets determined by the Apriori algorithm can then be used to discover association rules based on general trends in the dataset.

Data

This study uses data from the 2018 Oklahoma Beef Management and Marketing Survey conducted by the Oklahoma State University Department of Agricultural Economics in collaboration with the Department of Animal Science and the Oklahoma Cooperative Extension Service (IRB Approval No. AG1743). Since one goal of this research is to extrapolate the results into a broader reach for educational programming, we chose to sample the state producer population at large rather than to sample from existing extension or association participation lists. The United States Department of Agriculture's (USDA) National Agricultural Statistics Service (NASS) was contracted for sampling, distributing, data collection, and data entry. When drawing from their sample frame of Oklahoma cattle producers, NASS used a stratified sampling technique to generate survey results that are representative of the state's cattle producer population. A total of 5,000 surveys were sent with 1,495 surveys completed and returned, resulting in a 29.9% response rate. Of the 1,495 survey respondents, 48.76% were mail respondents while 51.24% were respondents via phone follow-up. This response results in a confidence level of 95% with a sample error of 4%. Approximately 1,210 respondents, i.e. 81%, reported being a cow-calf producer in the year under consideration. These cow-calf producers are the focus of this study.

The survey elicits information regarding producer adoption of various recommended production and marketing practices. We focus on seven management practices, including castration, horn management, deworming, feed bunk training, 45-day pre-marketing weaning period, respiratory vaccinations, and implant use. While our sample is unique to Oklahoma, recommendations regarding adoption and timing of these calf health management practices are similar across the U.S., implying that the insights obtained here should be generalizable for cow-calf operations. We apply market basket analysis to a subset of data that includes cow-calf producers who adopted at least one of these seven practices (n=1,108). Since market basket analysis searches for associations among practices, usable data includes only those cow-calf producers who reported adopting at least one of the seven practices.

Results and Discussion

Table 1 presents summary statistics of selected demographic information for producers included in the analysis. While demographic variables are not used in the market basket analysis, this information does illustrate the representativeness of the producers included in the sample. Approximately 44% of producers are 65 years or older, whereas only 3% are below age 35. This age distribution corresponds with that in other studies such as Williams et al. (2013), McBride and Mathew (2011) and USDA-NASS (2017), who find the percentage of producers above age 65 to be between 42% and 48% and those below 35 years old to be about 5% at both the state and national levels. A herd size of less than 100 head is most common, accounting for approximately 60% of producers, with only about 3% reported owning herd sizes of more than 500 head. This finding is consistent with previous surveys in Oklahoma (e.g., USDA-NASS 2017; Vestal et al. 2007) where the majority of producers owned less than 100 head. Measures of cattle income relative to household income show that cattle account for less than 40% of income for about 60% of producers, a finding similar to Vestal et al. (2007) where 80% of producers indicated that cattle income accounted for less than 40% of household income. Williams et al. (2013) found a similar pattern with cattle income accounting for less than 40% of household income among 76% of Oklahoma cow-calf producers.

Table 2 summarizes adoption rates for seven cow-calf management practices for those producers who adopted at least one of the seven practices (n=1108). Not surprisingly, the basic recommended practices of castration, horn management and deworming are the most widely adopted practices with adoption rates greater than 70% for each practice. Similarly, Williams et al. (2013) found castration to be the most widely adopted practice by Oklahoma cow-calf producers with 72% of producers reporting using the practice, while deworming was second at 62%. We find that slightly less than half (47%) of respondents reported dehorning their calves, but when combined with those who used polled genetics to ensure calves had no horns, horn management has the highest adoption rate of the seven practices for producers sampled here. The set of practices that are bundled with the three basic practices for preconditioning have lower adoption rates than the base practices, as expected, with respiratory vaccines reported by only 42% of producers. Finally, the percentage of producers who implant calves (20%) has fallen across time and the statistics here give further evidence that is true. Similar adoption rates for implants are reported in other studies (e.g., see Williams et al. 2013; Johnson et al. 2010).

Association Rule Results

A total of 448 association rules were discovered initially. The discovered rules are plotted against support, lift, and confidence (Figure 1) to help filter out bundles that fail to meet the minimum parameter (support, confidence, and lift) thresholds. We chose to filter out bundles with confidence values below 0.5, support values below 0.25, and lift values below 1.2, as indicated by the threshold lines in Figure 1. The support value filters out bundles that are more rare and the lift value denotes at least some degree of correlation among the practices. One noteworthy point from this plot is that many rules with high confidence and high lift also have low support, implying that these bundles are not widely adopted in the sample. These are the medium to dark diamonds in the far left segment of the chart. A closer inspection revealed that most bundles in this segment included implants as a consequent of almost all preconditioning practices (antecedent). Practice bundles in this segment represent just over 10% of the sub-sample. This is expected given the low adoption rate of implants. Given our minimum threshold specifications, 27 rules identifying likely practice bundles are discovered as listed in Table 3. These 27 rules all lie in the top right segment of figure 1 above the 1.2 minimum lift threshold line, to the right of the 0.25 minimum support threshold line, and are represented primarily by the darkest diamonds.

An assessment of the rules listed in Table 3 reveal that 7 of the 27 discovered association rules include all three of the practices that we and others have described as basic, including castration, horn management and deworming. Further, 15 association rules include at least two of these basic practices and 9 of those rules examine the third basic practice as a consequent with conditional probabilities above 0.90 in each case. The remaining 5 rules include at least one of the three practices. Horn management is present in 22 of the 27 association rules. The association rule with the highest level of support at 0.50 is the antecedent of horn management and deworming, likely the two simplest practices to implement, particularly if polled genetics are used for horn management. Association rules with the highest lift values (>1.50) all involve 45-day weaning as the consequent and, of those rules, only one includes all three basic practices in the antecedent. Recall that lift value greater than 1.0 imply that observed support of the antecedent and the consequent is larger than if the two were independent. Though premiums are typically highest for fully preconditioned calves, there is often a market premium for "long-weaned" calves as well, which may explain the relatively high lift values when 45-day weaning is the consequent.

We also examine the association rules among only the three basic practices. These results are reported in Table 4. Support levels across all combinations range from a low of 0.56 to a high of 0.63. Generally speaking, this would indicate that over half of the producers responding adopt at least two of the three basic management practices. Confidence values for the consequent practice adoption are also strong across the various combinations, ranging from 0.73 to 0.92, indicating that many producers in fact adopt all three basic practices. Interestingly, the lowest confidence values are reported when horn management alone is the antecedent, at 0.73 for castration as an antecedent and at 0.74 for deworm as the antecedent. This would suggest that though many producers are adopting the basic practices in some combination, there are more producers who implement horn management without adopting a consequent, though that number would appear to be relatively small.

Certainly there is still room for improvement in producer adoption of the three basic practices, both individually and in combination. However, given the relatively high adoption rates of those practices in this study and evidence from past studies (e.g. Williams et al. 2013; Schumacher, Schroeder and Tonsor 2012), we use this basic practices bundle as a starting point for further analysis of the conditional probabilities among antecedent bundles and potential consequent practices reported in Table 3. Figure 2 depicts a decision tree with a series of consequent practice adoption possibilities at different stages of the adoption hierarchy, given the bundle of castration, horn management and deworming as the initial antecedent. Conditional probabilities for consequent adoption of feed bunk training, 45-day weaning, and vaccinations individually when base practices have already been adopted, are 0.81, 0.71, and 0.57, respectively. That is, producers who adopt the antecedent base bundle have a significantly higher conditional probability of also adopting feed bunk training or 45-day weaning than vaccinations as a consequent. This difference in probabilities could be because some producers may opt to wean at 30 days prior to marketing rather than 45 days, yet still train calves to feed from bunks during the shorter weaning period. Also, vaccinations may require another run through the chute for calves which the non-adopter may choose not to do possibly because of preference, doubt of positive returns or a lack of resources (e.g. labor, time, knowledge).

Assuming the consequents for base practices are adopted, we can examine the probabilities that another preconditioning practice is jointly adopted. In the top row of figure 2, if the antecedent becomes base practices plus 45-day weaning, there is an 85% probability that the producer will also adopt feed bunks as a consequent. However, following the middle branch of figure 2, if a producer has implemented base practices plus feed bunk training, there is only a 75% probability that they will also adopt 45-day weaning. The conditional probability of vaccination as a consequent to the antecedent containing base practices plus 45-day weaning (0.68) is greater than if the antecedent contains base practices and feed bunks (0.62). If both 45-day weaning and feed bunk training comprise the antecedent bundle, the conditional probability for vaccination increases further to 70%. This perhaps indicates that producers understand the health impacts associated with weaning and are more likely to vaccinate calves if they adopt both 45-day weaning and feed bunks in addition to the base, as it would be the component that would complete a preconditioning program. It is interesting to also note that the conditional likelihood of 45-day weaning (0.85) is higher if the antecedent contains vaccinations in addition to base practices than if the antecedent contains only base practices. The same pattern is observed with regards to feed bunks, and reinforces the earlier explanation in the sense that producers appear to be more likely to implement 45-day weaning and feed bunks conditional on base practices plus vaccination. Taken together, these results suggest that producers are cognizant of the health benefits of vaccination, particularly if calves undergo 45-day weaning and feed bunk training. It also likely reflects the influence of VAC-45 programs, as producers who choose to enroll in these programs are required to wean calves a minimum of 45 days and vaccinations are a required component of the protocol, along with the base practices and bunk training.

Implants are not necessarily part of a preconditioning program and are less widely adopted than the other practices considered here, though research indicates that implants improve production efficiency and gain (e.g. Lopez-Campos et al. 2013). Recent educational programming emphasizes the benefits of incorporating implants into calf management for cow-calf operations who are not participating in process-verified programs that prohibit it in order to target niche beef markets. Because of this educational effort, we examined the likelihood of implant adoption under three different scenarios: 1) castration only as an antecedent; 2) three base practices as antecedent; and 3) all 6 preconditioning practices as an antecedent. Results of this analysis (Figure 3) indicate the conditional probability of implant adoption increasing with the number of practices already adopted. In scenario 1 with castration as the antecedent, the conditional probability of the producer also implanting calves as a consequent is only 0.27. With the three basic practices as antecedent (scenario 2), the conditional probability of implanting calves is 0.32, an increase of 5 percentage points from the scenario where castration only is the antecedent. In scenario 3 when all 6 preconditioning practices are bundled as the antecedent, the conditional probability of implant adoption as a consequent increases to 0.42. Thus, efforts to improve adoption of implants may benefit from initially targeting producers who are already implementing a preconditioning program, as these are more likely to adopt implants. This may be partially attributable to the fact that calves held for a longer weaning period have ample time on the ranch to respond to the implant regarding feed efficiency and gain before marketing. That is, the producer has time during the longer preconditioning period to more fully capture the economic benefits of implant-induced production efficiencies.

Conclusions

Market basket analysis is a useful tool for learning more about how cow-calf producers bundle various recommended management practices. It informs decision modeling by relaxing the assumption of adoption independence among recommended management practices. Association Rule learning with market basket analysis and the Apriori algorithm finds varying conditional probabilities for joint adoption among practices. Results show that horn management, deworming, and castration are the more commonly adopted practices and also are commonly jointly adopted as a bundle. Based on those results, we construct a hierarchy of practice adoption leading to preconditioning based on those three practices (horn management, deworming, and castration) as the initial antecedent bundle and on the conditional probabilities of various practices as sequenced consequent bundles, including feed bunk training, a 45-day weaning period and respiratory vaccinations. Presuming that base practices are implemented and that a producer is also feed bunk training, the probability of also implementing 45-day weaning is lower than if those two practices are reversed in the scenario. One plausible explanation for this result is that producers may offer bunk training regardless of the length of weaning time prior to marketing. For example, they might choose to wean calves for a shorter period, e.g. 30 days, yet still adopt feed bunk training during the weaning period. A primary finding of this research is that, based on conditional probabilities, respiratory vaccinations appear to be the last piece of the puzzle for completing the preconditioning bundle. That is, among the three recommended health management practices that would be adopted with the base practices to complete most preconditioning protocols, vaccinations always carry the lowest conditional probability value as a consequent practice, regardless of the antecedent bundle. It could be that producers associate vaccinations with a higher work load in terms of processing calves. It is also true that long-weaned calves, i.e. calves weaned over 45 days, often bring market premiums, even if those premiums tend to be lower than fully preconditioned calves, and producers may not perceive the additional benefit of vaccinating to be worth the cost in time and resources.

Implants, which are implemented by only 20% of producers in the sample, are evaluated under three different scenarios: with castration only; with the basic bundle of horn management, deworming, and castration; and with the six preconditioning bundle practices. Results indicate that the conditional probability of a producer using implants increases as the antecedent practice bundle moves from castration to the basic practices to the full preconditioning protocol. This may reflect that producers presume implants have more time to work when a longer weaning period is implemented, allowing them to potentially capture more value. It may also reflect a misunderstanding of the value of non-implanted cattle at marketing if those animals are not in a process verified program or a lack of knowledge of the potential for earlier implant protocols.

Educational programming regarding calf health management practice adoption seeks to meet producers "where they are" with respect to practice adoption to provide objective information about practice implementation, including benefits to the beef supply chain as well as benefits and costs to the producer of both individual practices and practice bundles. Identification of commonly bundled practices and conditional adoption probabilities of various consequent practices can help identify possible practice adoption hierarchies and frequent antecedent bundles. In doing so, we can begin to identify why some practices tend to be bundled together but not others and, importantly, we can begin to identify practice adoption gaps. These practice adoption gaps may be cases where producers are not bundling practices that from a technical standpoint are relatively easy to bundle but they have a corresponding knowledge gap. That knowledge gap could be about technique or timing for example. Alternatively, practice adoption gaps may occur because of a lack of adequate resources for implementation. Gaps may also occur because producers doubt the return for their efforts. As we learn more about where gaps exist, we also learn more about how to educate and how to facilitate adoption of calf health management practices. From a policy perspective, recommended calf health management practices produce calves that have fewer health problems and higher productivity as they move through the beef supply chain. Healthier calves require less medical attention and, by logic, fewer antibiotic treatments.

Future studies can build on the identified hierarchies and practice bundles to model adoption decisions of demographic groups using constructed bundles, thus relaxing the independence assumption. However, the results also highlight the need for a closer examination of which producers are more likely to adopt certain practice bundles, i.e. put them in their market basket, than others. Additionally, useful further research could examine why some producers with a certain antecedent bundle choose to adopt specific subsequent practices, while others do not. It could be that when implementation timing is flexible with antecedent practices but not with the consequent practices considered, the producer's timing decision influences whether the consequent is adopted. Producer access to labor, cattle handling facilities, equipment and other resources may also influence joint adoption combinations. Our results inform the type of questions that we should be asking ourselves as educators and asking of individual producers. For example, practice bundling may vary by demographic characteristics. It is the case for individual practices, so we expect that those characteristics would also influence bundling choices. This research is a first step to identify overall bundling "habits" that can then be further analyzed in a demographic context. Then we can begin to identify, for example, for those bundles where one more practice would complete the preconditioning protocol, who is that group and how do we help them take the next step?

Retailers use market basket analysis to glean information on which products to pair in promotions, store placement, and what recommendations to provide to customers – all in order to increase profitability. As researchers and extension educators, we can use market basket analysis to identify which combinations of research-based recommended calf health management practices are bundled frequently on the ranch, which are less so, and to gain insight as to how to help producers both recognize their importance and assist them in practice implementation to increase profitability through joint adoption of practices.

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References

Agrawal, R., H. Road, and S. Jose. 1993. "Mining Association Rules between Sets of Items in Large Databases." In *Proceedings of ACM SIGMOD Conference Washington DC. USA*. pp. 1–10.

Agrawal, R., and R. Srikant. 1994. "Fast Algorithms for Mining Association Rules." In *Proceedings of The 20th International Conference on Very Large Data Bases (VLDB 1994)*, pp. 487-499.

Beef Quality Assurance, 2019. "Beef Cattle Care and Handling Guidelines." Available at https://www.bqa.org/Media/BQA/Docs/cchg2019.pdf. Accessed 4-20-2020.

Behrends, L., T.G. Field, and K. Conway. 2001. "The Value of Information as Perceived by Feedlot Managers." *Animal Sciences Research Report, Fort Collins, CO. Colorado State University, Cattle Industry Reference Guide.*

Brin, S., R. Motwani, J.D. Ullman, and S. Tsur. 1997. "Dynamic Itemset Counting and Implication Rules for Market Basket Data." *ACM SIGMOD Record* 26(2):255–264.

Dhuyvetter, K.C., A.M. Bryant, D.A. Blasi, N.C. Edwards, M.R. Langemeier, J.B. Morgan, and C.W. Shearhart. 2005. "Preconditioning Beef Calves: Are Expected Premiums Sufficient to Justify the Practice?" *The Professional Animal Scientist* 21(6):502–514. https://doi.org/10.15232/S1080-7446(15)31256-0

Hahsler, M., B. Grün, and K. Hornik. 2005. "arules - A Computation Environment for Mining Association Rules and Frequent Item Sets." *Journal of Statistical Software* 14(15):1–25. http://dx.doi.org/10.18637/jss.v014.i15

Hipp, J., U. Güntzer, and G. Nakhaeizadeh. 2007. "Mining Association Rules: Deriving a Superior Algorithm by Analyzing Today's Approaches." In *European Conference on Principles of Data Mining and Knowledge Discovery* (pp. 159-168). Springer, Berlin, Heidelberg.

Johnson, R.J., D. Doye, D.L. Lalman, D.S. Peel, K. Curry Raper, and C. Chung. 2010. "Factors Affecting Adoption of Recommended Management Practices in Stocker Cattle Production." *Journal of Agricultural and Applied Economics* 42(1):15–30. https://doi.org/10.1017/S1074070800003266

Linoff, G.S., and J.A. Berry, Michael. 2011. *Data Mining Techniques for Marketing, Sales, and Customer Relationship Management* 3rd ed. Hoboken, NJ: Wiley Computer Publishing.

Lopez-Campos, O., J. L. Aalhus, E.K. Okine, V.S. Baron, and J.A. Basarab 2013. "Effects of Calf- and Yearling-fed Beef Production Systems and Growth Promotants on Production and Profitability." *Canadian Journal of Animal Science* 93(1):171-184. https://doi.org/10.1139/CJAS2012-035

McBride, W.D., and K.J. Mathew. 2011. "Diverse Structure and Organization of US Beef Cow-Calf Farms." No. 102764. United States Department of Agriculture, Economic Research Service.

Popp, M.P., M.D. Faminow, and L.D. Parsch. 1999. "Factors Affecting the Adoption of Value-added Production on Cow-Calf Farms." *Journal of Agricultural and Applied Economics* 31(01):97–108. https://doi.org/10.1017/S0081305200028806

Pruitt, J.R., J.M. Gillespie, R.F. Nehring, and B. Qushim. 2012. "Adoption of Technology, Management Practices, and Production Systems by U.S. Beef Cow-Calf Producers."

Journal of Agricultural and Applied Economics 2(May):203–222. https://doi.org/10.1017/S1074070800000274

Schumacher, S., K.C. Raper, and D.S. Peel. 2017. “Demographic Influences on Nonadoption of Calf Management and Marketing Practices for Cow-Calf Operations.” *Journal of Applied Farm Economics* 1(2). 10.22004/ag.econ.302993

Schumacher, T., T.C. Schroeder, and G.T. Tonsor. 2012. “Willingness-to-Pay for Calf Health Programs and Certification Agents.” *Journal of Agricultural and Applied Economics* 44(2):191–202. https://doi.org/10.1017/S1074070800000262

Shaw, M.J., C. Subramaniam, G.W. Tan, and M.E. Welge. 2001. “Knowledge Management and Data Mining for Marketing.” *Decision Support Systems* 31(1):127–137. https://doi.org/10.1016/S0167-9236(00)00123-8

United States Department of Agriculture - National Agriculture Statistics Services (USDA-NASS). 2009. “2007 Census of Agriculture: United States Summary and State Data.” Available at: http://www.agcensus.usda.gov/Publications/2007/Full Report/usv1.pdf

Vestal, M., C. Ward, D. Doye, and D. Lalman. 2007. “Cow-Calf Production Practices in Oklahoma – Part 1.” Oklahoma Cooperative Extension Service. AGEC-245.

Ward, C., M. Vestal, D. Doye, and D.L. Lalman. 2008. “Factors Affecting Adoption of Cow-Calf Production Practices in Oklahoma.” *Journal of Agricultural and Applied Economics* 40(3):851–863. https://doi.org/10.1017/S1074070800002376

Williams, B.R., K.C. Raper, E. A. DeVuyst, D. Peel, D. Lalman, and C. Richards. 2013. “Demographic Factors Affecting the Adoption of Multiple Value-Added Practices by Oklahoma Cow-Calf Producers.” *Journal of Extension* 51(6).

Williams, G.S., K.C. Raper, E.A. DeVuyst, D. Peel, and D. McKinney. 2012. “Determinants of Price Differentials in Oklahoma Value-Added Feeder Cattle Auctions.” *Journal of Agricultural and Resource Economics* 37(1):114–127. https://doi.org/10.22004/ag.econ.122309

Yabing, J. 2013. “Research of an Improved Apriori Algorithm in Data Mining Association Rules.” *International Journal of Computer and Communication Engineering* 2(1):25–27.

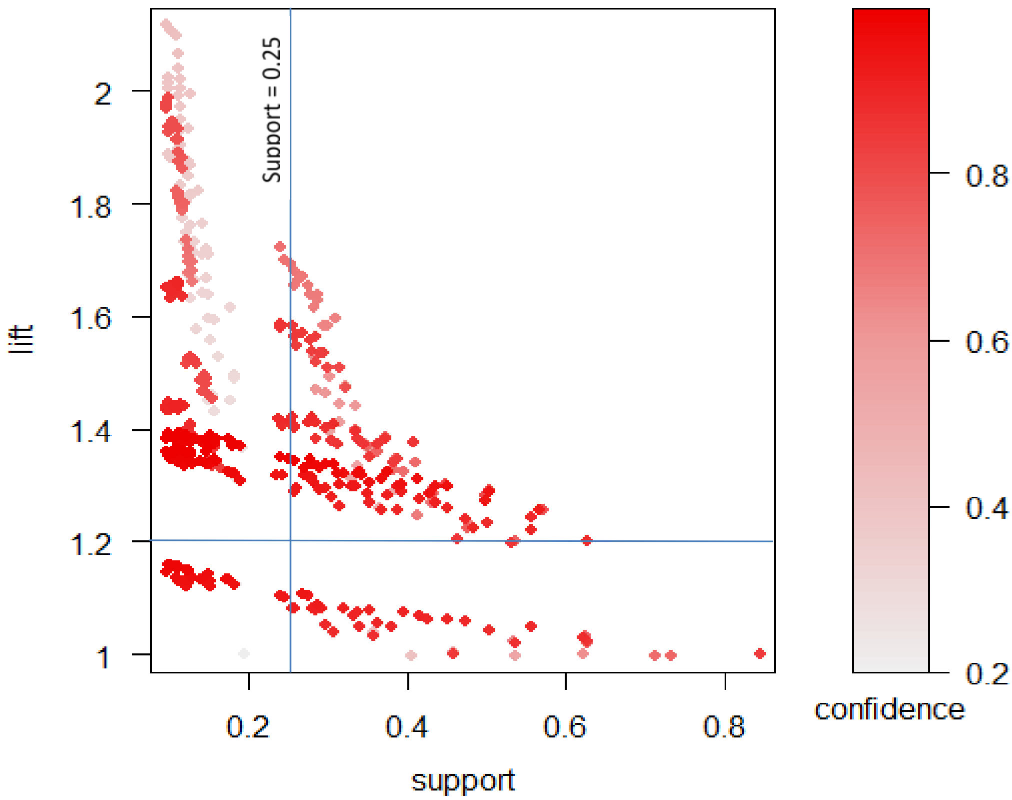

Figure 1. Scatter Plot of Association Rules by Support, Confidence and Lift

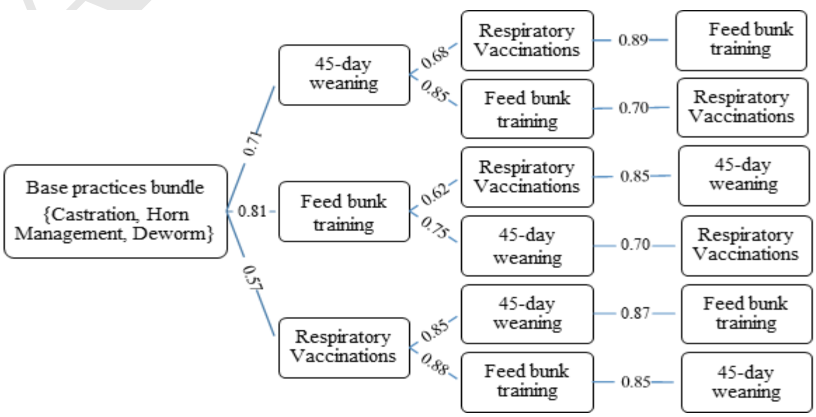

Figure 2. Probability of Joint Adoption for Selected Antecedent and Consequent Calf Management Practice Combinations

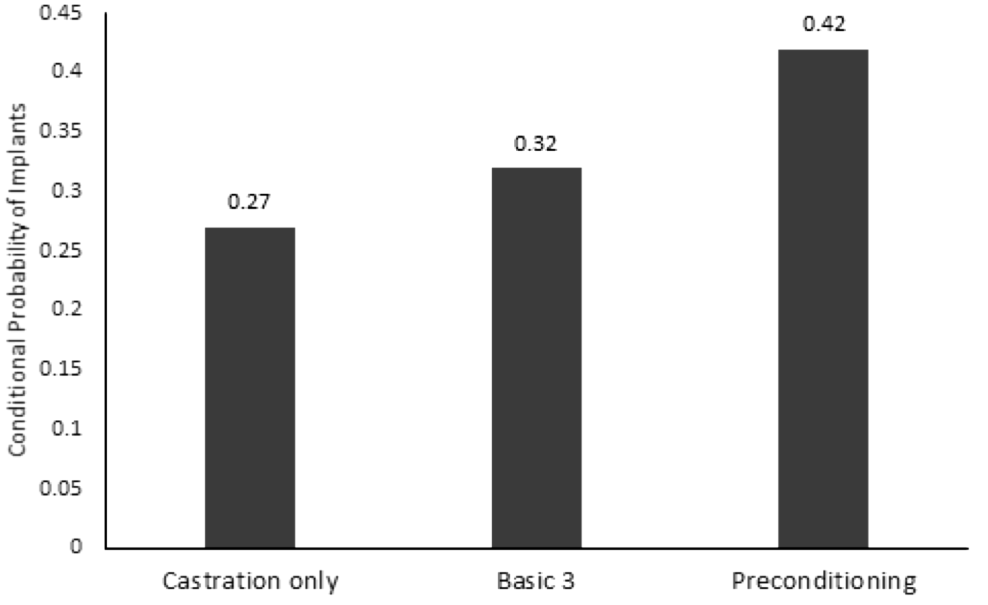

Figure 3. Probability of Implant Adoption under Three Antecedent Scenarios
Note: Basic 3 = {Castration, Horn Management, Deworm}
Preconditioning = {Basic 3 + {Feed bunk training, vaccinations, 45-day weaning period}}

Table 1. Demographics for Producers Adopting at Least One Listed Practice (n=1108)a

Variable	Number of Producers	Percent of Producer Sample
Age		
<=25	2	0.2
25-29	9	0.9
30-34	19	1.9
35-39	34	3.4
40-44	45	4.5
45-49	59	5.9
50-54	86	8.6
55-64	288	28.7
65-74	283	28.2
>= 75	158	15.8
Not reported	20	2
Herd Size		
1-24	160	16
25 - 49	195	19.4
50 - 99	244	24.3
100 - 249	270	26.9
250 - 499	88	8.8
500 - 749	26	2.6
750 - 999	5	0.5
1000+	8	0.8
Not reported	7	0.7
Percent Cattle Income		
0	66	6.6
1-20	375	37.4
21 - 40	201	20
41 - 60	133	13.3
61 - 80	86	8.6
81 - 100	75	7.5
Not reported	67	6.7

[a]*Castration, Horn management, Deworming, Minimum 45 day weaning, Respiratory vaccinations, Bunk training, Implants*

Table 2. Adoption Rates of Producers Adopting at Least One Listed Practice (n=1108)

Practice	%
Base Practices	
Castration	71
Horn Management	77
Polled genetics	29
Deworm	73
Preconditioning Practices	
45-day weaning	53
Respiratory vaccines	42
Feed bunk training	63
Other	
Implant calves	20

Table 3. Market Basket Analysis Practice Adoption Association Rules with Associated Support, Confidence and Lift

Antecedent		Consequent	Support (min=0.25)	Confidence (min=0.5)	Lift (min=1.2)	Count
{feed bunk, castration, horn mgmt, vaccination}	=>	{deworm}	0.28	0.98	1.34	310
{feed bunk, castration, vaccination}	=>	{deworm}	0.31	0.97	1.33	340
{castration, horn mgmt, vaccination, 45-day weaning}	=>	{deworm}	0.27	0.97	1.33	299
{castration, horn mgmt, vaccination}	=>	{deworm}	0.32	0.96	1.32	353
{castration, horn mgmt, 45-day weaning}	=>	{deworm}	0.4	0.95	1.3	438
{horn mgmt, deworm, vaccination, 45-day weaning}	=>	{castration}	0.27	0.94	1.32	299
{horn mgmt, vaccination, 45-day weaning}	=>	{castration}	0.28	0.94	1.32	307
{feed bunk, horn mgmt, deworm, vaccination}	=>	{castration}	0.28	0.94	1.31	310
{horn mgmt, deworm, vaccination}	=>	{castration}	0.32	0.93	1.3	353
{feed bunk, horn mgmt, deworm, 45-day weaning}	=>	{castration}	0.34	0.93	1.3	376
{horn mgmt, deworm, 45-day weaning}	=>	{castration}	0.4	0.92	1.29	438
{castration, horn mgmt, deworm, vaccination}	=>	{feed bunk}	0.28	0.88	1.41	310
{castration, horn mgmt, deworm, 45-day weaning}	=>	{feed bunk}	0.34	0.86	1.38	376
{castration, horn mgmt, deworm, vaccination}	=>	{45-day weaning}	0.27	0.85	1.57	299
{castration, horn mgmt, 45-day weaning}	=>	{feed bunk}	0.35	0.84	1.35	388
{horn mgmt, deworm, vaccination}	=>	{45-day weaning}	0.29	0.84	1.56	318
{feed bunk, castration, deworm, vaccination}	=>	{45-day weaning}	0.26	0.84	1.56	285
{castration, horn mgmt, vaccination}	=>	{45-day weaning}	0.28	0.84	1.56	307
{feed bunk, castration, vaccination}	=>	{45-day weaning}	0.26	0.83	1.54	290
{feed bunk, deworm, vaccination}	=>	{45-day weaning}	0.28	0.83	1.54	308
{horn mgmt, vaccination}	=>	{45-day weaning}	0.3	0.83	1.54	327
{castration, deworm, vaccination}	=>	{45-day weaning}	0.29	0.83	1.54	321

{castration, horn mgmt, deworm}	=>	{feed bunk}	0.45	0.81	1.3	499
{horn mgmt, deworm}	=>	{feed bunk}	0.5	0.8	1.28	554
{feed bunk, castration, horn mgmt, deworm}	=>	{45-day weaning}	0.34	0.75	1.4	376
{castration, horn mgmt, deworm}	=>	{45-day weaning}	0.4	0.71	1.32	438
{castration, horn mgmt, deworm}	=>	{vaccination}	0.32	0.57	1.41	353
{castration, horn mgmt, deworm, vaccination, 45-day weaning}	=>	{feed bunk}	0.23*	0.87	1.42	265
{castration, horn mgmt, deworm, feed bunk, vaccination}	=>	{45-day weaning}	0.24*	0.85	1.59	265

**Included for comparison discussion in Figure 2.*

Table 4. Market Basket Analysis Association Rules among Basic Practices, with Associated Support, Confidence and Lift

Antecedent		Consequent	Support	Confidence	Lift	Count
{castration}	=>	{horn management}	0.62	0.87	1.03	688
{castration}	=>	{deworm}	0.62	0.89	1.22	694
{castration, horn management}	=>	{deworm}	0.56	0.9	1.22	615
{castration, deworm}	=>	{horn management}	0.56	0.89	1.05	615
{horn management}	=>	{castration}	0.62	0.73	1.03	688
{horn management}	=>	{deworm}	0.63	0.74	1.02	695
{horn management, castration}	=>	{deworm}	0.56	0.9	1.22	615
{horn management, deworm}	=>	{castration}	0.56	0.88	1.24	615
{deworm}	=>	{castration}	0.62	0.88	1.22	694
{deworm}	=>	{horn management}	0.63	0.86	1.02	615
{deworm, horn management}	=>	{castration}	0.56	0.92	1.29	695
{deworm, castration}	=>	{horn management}	0.56	0.89	1.21	615