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Data on data: An analysis of data usage and analytics in the agricultural supply chain

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Abstract

The amount of data being collected throughout the agricultural supply chain has increased in both volume and velocity. All signs indicate that this will only increase as data collection technologies become more cost effective and prevalent throughout the supply chain. Previous work in this area has focused on data collection at the farm level. Our study focuses on data that originates at five different stages of the agricultural supply chain off the farm and how these stages view their firm's data collection and analysis efforts. We find that there is heterogeneity in the data collection efforts and analysis across the agricultural supply chain. Improved customer satisfaction and improved decision making were the most important benefits to data collection. We also find that the expected benefits and challenges for implementation of these efforts are not universal. Companies that exist upstream in the supply chain are more likely to disagree on intended benefits and challenges.

KEYWORDS

agribusiness, data, data analytics, supply chain

INTRODUCTION AND MOTIVATION

The McKinsey Global Institute ranked agriculture as the least digitized industry across the 22 United States industries assessed in their digitization index. The food industry, identified in

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the study within the basic goods manufacturing and retail trade sectors, indicates slightly higher advancement in digitization. It, however, also stands as a laggard in the digital revolution, showing that all stages of the agricultural supply chain have substantial room for improvement (Manyika et al., 2015). To exemplify the magnitude of digitization's importance to the U.S. economy, considering three key areas (the labor market, capital efficiency, and multifactor productivity), the impact on future economic growth could add up to $2.2 trillion by 2025 (Manyika et al., 2015). Even though there is no specific number for the food and agriculture industries, considering that agribusiness-related industries combined generated $2.8 trillion in revenue in 2021, it is clear that the impact on these industries could be significant, especially if them being laggards in digitization is taken into consideration (Madigan, 2021).

Significant investments have been made and are continuing to be made to bridge this gap and the growth of ag-tech startups illustrates this perspective. Startups in this sector raised $26.1 billion in 2020, adding to over 3000 deals and over 2700 unique investors, representing 34.5% monetary growth over 2019. These investments were divided between upstream (i.e., farm product and services providers) companies with 60% of the total dollar amount and 40% for downstream companies (e.g., food retail) (Agfunder, 2021).

Data are an important company asset that can provide a competitive advantage because it allows for insights that drive strategic decisions and helps forecast future results. However, agribusinesses must have the right set of skills and assets to leverage the data they have acquired. Through data analytics and a defined strategy, a company may attain and hopefully sustain a competitive advantage (Grant, 1991; Pham & Stack, 2018). The process of data analytics that turns data into insights may be costly or unattainable for many companies, which means that not all companies are getting the same value and insights from the available data.

However, despite this recent attention, little is known about data and data analytics use across the different entities that compose the agricultural supply chains. Previous studies have either focused on specific applications or specific stages of the supply chain, with particular attention paid to the data generated at the farm level (Bronson & Knezevic, 2016) and to on-farm adoption of data technologies (Birner, Daum, & Pray, 2021; Khanna, 2021).

Although the amount of data collected from farms, agribusinesses, and food companies is growing rapidly, little is known about how different food and agricultural supply chain players collect data and use it to gain insights into their business. Anecdotally, we know it is happening as we would not observe the current level of investment otherwise, but we have yet to examine it in depth. Could there be specific sectors of the agricultural supply chain that are more prolific at collecting and analyzing data? Therefore, this research's objective is to explore data usage at various stages of the agricultural supply chain outside of the farm. We will also examine how organizations in different stages of the agricultural supply chain perceive their companies' data collection and data analytics and how this may translate into value for the company.

A survey across the different parts of the agriculture and food value chain was employed to tackle these questions. Participants at the various levels of that chain were asked how they perceive data usage, benefits, and challenges, and the overall importance this topic has in their decision-making process.

Previous work has shown that data applications can empower farmers to increase efficiency and create value (Jayashankar, Johnston, Nilakanta, & Burres, 2019). This helps explain why there has been much discussion about data in agriculture recently (OECD, 2019; World Bank, 2019). Moreover, a great deal of current research effort focuses on data in the agricultural and food industry, for example, regarding its governance. This topic has direct and strong implications on policymaking since factors such as overcoming free-riding with member benefits to

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data providers, ensuring data interoperability with uniform data standards, and controlling data access and use with cooperative governance are shown to be important attributes when considering data governance (Hutchins & Hueth, 2022) Another area where research has been evolving rapidly is about data ownership in the context of farmland markets. As the cornerstone of the agricultural sector, land prices and lease contracts have a major impact on this industry. When farmers are granted property rights on the data they generate in their operations, they can choose the best way to leverage this data by sharing it with entities that value it in a way that benefits them and, in turn, improves farmland markets by addressing information problems and enhancing the underlying value of farmland (DeLay, Boehlje, & Ferrell, 2022).

This study complements other ongoing research efforts like the ones mentioned prior in different ways. First, policy initiatives that seek to connect various sectors of the supply chain need to know where bottlenecks of information exist or what parts of the supply chain present challenges. More than that, these policies need to be put in place to address matters of data ownership, data governance, and data privacy, together with advances in institutions for data sharing, to create opportunities to broaden access and reduce the transaction costs of accessing agricultural data while preserving confidentiality where necessary. These developments provide opportunities to improve policies by helping overcome information gaps and asymmetries, lowering policy-related transaction costs, and enabling people with different preferences and incentives to work better together, ultimately creating a more transparent and resilient system (OECD, 2019). With that, this research helps policymakers and managers understand the current situation and perception of data collection and use by different links of the agricultural and food value chain, giving insight into where actions can be more impactful. It also focuses on the challenges and benefits companies in those areas perceive on data usage, providing crucial information on barriers to be removed and gains to be enhanced.

SURVEY AND METHODOLOGY

Survey data

The Center for Food and Agricultural Business at Purdue University conducted a survey sent to companies representing five stages of the agricultural supply chain. The levels of the supply chain used for this survey were the following: (1) agricultural input manufacturers, (2) agricultural retailers, (3) first handlers/food processors, (4) food manufacturers, and (5) food retailers. Agricultural retailers and agricultural input manufacturers being pre-farm gate, or upstream from the farmer, and first handlers/food processors, food manufacturers, and food retailers being post-farm gate or downstream from the farmer.

Agricultural input manufacturers represent many different products and services critical to agriculture. Those range from fertilizers ($27.2 billion in revenue in 2021), crop protection (with $15.9 billion in revenue in 2021), animal feed ($34.4 billion in revenue in 2021), equipment and other ($71.58 billion in revenue in 2021), to many others (Curran, 2021a; Madigan, 2021; Ristoff, 2022a; Ristoff, 2022b).

Agricultural retailers, who provide the connection between the agricultural input manufacturers to the farming operations by selling these inputs to farmers, generated about $137 billion in 2021. This number does not take into consideration crop services, which generated another 26.8 billion in the same year (Burns, 2021; Curran, 2021b).

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Food first handlers like ADM, Bunge, Cargill, and many others are the companies that buy the outputs from farming operations and sell those as inputs to food manufacturers. They may also transform those agricultural goods by crushing, shelling, sorting, etc., and then provide the resulting goods as inputs to companies like food manufacturers. To exemplify the size and importance of this link in the value chain, just on soybean processing, more than $33 billion were generated in revenue in 2021 (Thomas, 2021).

Food manufacturers represent the largest sector of this value chain, with revenue of $837 billion in 2021. These companies take the products sold by the first handlers and transform them into finished products to be offered to final consumers through various channels like retail, restaurants, catering, etc. Finally, food retailers (represented by supermarkets and grocery stores) that connect food production to the final consumers generated over $811 billion in revenue in 2021 (Diment, 2022).

TABLE 1 Survey respondent demographics.

Respondent role within organization	Percentage of responses	Number of respondents
Sales	27%	374
Executive or upper management	17%	236
Operations	13%	180
Marketing	13%	180
Other	12%	166
Service	7%	97
Human resource	4%	55
Procurement	3%	42
Outbound logistics	2%	28
Inbound logistics	2%	28
Company size		
>1000 employess	36%	499
100–1000 employess	36%	499
10–99 employess	20%	277
Fewer than 10 employess	8%	111
Agricultural supply chain sector		
Agricultural input manufacturer	30%	416
Agricultural Retailer / Dealer	25%	346
Processor / Trader / First Handler	17%	236
Food manufacturer	16%	222
Food retailer	12%	166
Years of company existence		
>50 years	42%	582
10–50 years	37%	513
5–10 years	15%	208
<5 years	6%	83

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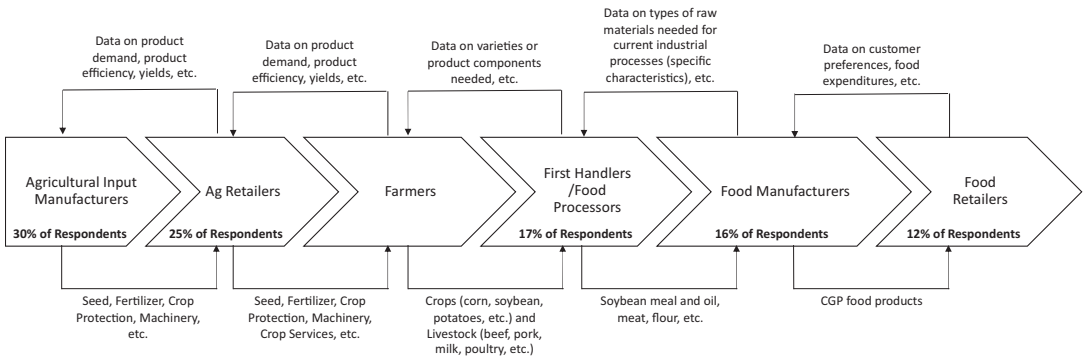

FIGURE 1 Organization of the agricultural supply chain, flows of data and goods, and segment participation in the survey.

The survey was conducted from May to July 2019, with e-mails being sent to employees who served as points of contact (convenience sample) in companies in each analyzed segment with an explanation of the research they were being asked to participate in and a link to the online survey. Those people were then asked to forward the survey link to other members of their companies. More than 1800 individuals who work in the agricultural supply chain responded to the survey, and after data cleaning, 1386 were considered usable responses. Survey participants were asked about their organization's data collection, data analytics, and the benefits and challenges of analytics. The questions were: to what extent does your organization collect data that is useful, approximately what percentage of overall decisions are made based on data analytics in your organization, what do you see as the most important benefit of data analytics, and please rate the importance of data-related challenges in your organization.

The survey targeted all functions of an agribusiness, and the 1386 respondents were divided into each segment of the food and agricultural business supply chain (see Table 1 for the demographics of the survey respondents). It is important to mention that our survey did not represent each segment of the value chain proportionally to any specific metric, such as revenue. This survey presented 55% of the respondents on the "upstream" side of the value chain (30% from agricultural input manufacturers and 25% from agricultural retailers). Forty-five percent of the respondents (17% from first handlers/food processors, 16% from food manufacturers, and 12% from food retailers) were from the "downstream" part of the value chain (Figure 1).

Employees working in agricultural input manufacturers were the most represented with 30% of the survey responses, whereas employees working at food retailers had the lowest representation of 12% of the data.

The survey targeted various job business functions to explore the different perspectives in those companies. Several job positions were surveyed, with workers belonging to the sales function of the agribusinesses being the most represented at 27% of the sample, managers (in various levels) are 17% of the respondents, followed by workers in operations at 13%, then marketing at 13%.[1] Respondents were also asked about the size of the company they belong to, captured by its number of employees. Of the 1386 individuals represented in this survey, 36% work in an organization with more than 1000 employees, 36% between 100 to 1000 employees, and 29% in companies with less than 100 employees.

Another demographic the survey asked about was the company's experience, represented by the number of years the organization has been active in the industry. Forty-two percent of

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respondents said that their organization has been in the industry for more than 50 years, 37% were from companies that have been active for 10–50 years, 15% have been active between 5 and 10 years, and 6% of the sample represented organizations with five or fewer years of activity in the industry. Overall, this indicates that the companies represented in the sample skew toward being more mature companies with experience in the agricultural sector.

Statistical tests of means

The bulk of the analysis for this research will be analyzing the percentage of respondents that indicated how their company collects data and to what extent their company uses that data in making decisions. However, the questions concerning the benefits and challenges of data collection were asked in a ranked-choice and Likert scale format. Thus, the means of the responses will be analyzed. Therefore, comparing the statistical significance in the means of these two questions is prudent.

For the question regarding the benefits of data, a Kruskal–Wallis[2] test was conducted, followed by a post-hoc Conover test, with Bonferroni correction, to identify means that are statistically different from one another. Because this question has discrete, non-continuous responses (non-parametrical), simple mean difference tests cannot be deployed. A Kruskal–Wallis test has the null hypothesis that there is no statistical difference in rankings across groups. While the Kruskal–Wallis test is useful in determining if differences exist across

TABLE 2 Data collection across agricultural supply chain and respondent role within organizations.

Ag supply chain sector	Collects extensive data	Collects some data	Collects No data
Overall	42.94%	49.20%	7.86%
Agricultural Input Manufacturer	50.46%	46.30%	3.24%
Agricultural Retailer / Dealer	38.72%	55.99%	5.29%
Processor / Trader / First Handler	41.39%	50.82%	7.79%
Food Manufacturer	46.72%	43.23%	10.04%
Food Retailer	30.06%	47.98%	21.97%
Respondent Role within Organization	**Collects Extensive Data**	**Collects Some Data**	**Collects No Data**
Executive or Upper Management	44.93%	52.90%	2.17%
Human Resource	43.40%	43.40%	13.21%
Inbound Logistics	70.83%	25.00%	4.17%
Marketing	51.74%	43.02%	5.23%
Operations	49.15%	44.07%	6.78%
Other	50.81%	45.41%	3.78%
Outbound Logistics	29.03%	48.39%	22.58%
Procurement	52.63%	42.11%	5.26%
Sales	39.05%	51.78%	9.17%
Service	44.90%	36.73%	18.37%

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rankings within groups, it cannot tell which groups are statistically different. Thus, a post-hoc Conover test with Bonferroni[3] correction is employed to identify the means of groups that are statistically different from others. The null hypothesis is that there is no difference between two particular means of the ranking question. The null hypothesis is rejected if the difference between the group means is larger than the test statistic value.

For the question regarding data-related challenges, an ANOVA test was used to verify if there are significant differences between the means for each level of the supply chain and the entire sample. Since this question has parametric responses, this test is considered more efficient at comparing means. After that, due to the detection of differences in at least one mean among the options, a Tukey HSD (Honestly Significant Difference) test was conducted to identify the options with statistically different means.

RESULTS AND DISCUSSION

Level of data collection

The respondents were asked to classify to what extent their companies collected useful data. The definition of what constitutes useful data was not provided, giving them the possibility to apply their personal view of how data can be useful to their company. Results for this question for the five different levels of the agricultural supply chain are in Table 2.

Overall, all the levels of the supply chain perceive that they collect some or extensive useful data, ranging from 97% of respondents in the agricultural input manufacturers group to 78% for food retailers. On average, 43% of the respondents for the entire sample said that their companies collect useful data extensively, 49% collect some useful data, and only 8% answered that their companies collect no useful data. This result is in line with many studies that state the importance of data and its collection for companies (Ingram & Maye, 2020; OECD, 2019; World Bank, 2019). While no time series of this data exists, these results show that the investments have led to 92% of the agribusinesses surveyed to indicate that they either extensively collect data or collect some data. This shows that a data-driven culture is perceived as a good way to conduct business in companies across many industries, including the food and agricultural sector (Eastwood, Ayre, Nettle, & Dela Rue, 2019).

The agricultural input manufacturers group had the highest percentage of respondents that perceived their company as extensively collecting useful data, with 50%. Agricultural input manufacturers also had the lowest percentage of respondents that indicated that their organization collects no useful data at 3%. The agricultural supply chain sector with the lowest response rate for their organization extensively collecting data was food retailers (30%). Food retailers also had the highest percentage of respondents stating that their company collects no useful data, with 22% of food retailer employees indicating that their organization collects no useful data.

These findings have several important implications. First, it shows that the level of data collection across the agricultural supply chain is not uniform. Various sectors of the agricultural supply chain collect different amounts of useful data. Secondly, and this point is something that does need to be explored further, it appears that the threshold for what is considered useful data is also not universal.

Both food retailers and processors/traders/first handlers are sectors of the supply chain that, at first glance, have large quantities of data. Food retailers have customer reward programs to

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track customer purchasing trends, and processors/traders/first handlers have data on harvests, ending stocks, and yields, to name a few types of data available. This may signal that the types of data they collect may not be very useful or there could be data they would like to obtain but have to be able to acquire it. For instance, food retailers continually attempt to monitor inventory and inbound logistics for fresh fruit and vegetables.

Food retailers are the gatekeepers to the end consumer along the supply chain and are the first to see the products demanded by end consumers and to communicate this message upstream in the chain. They also have the largest customer base and have adapted accordingly to track their customers' purchasing habits with reward and loyalty programs. It is possible to argue that point-of-sale data, shopper surveys, shelf-space analytics, and numerous other sources of data collected at most food retailing organizations today are far more extensive any other sector in the agricultural supply chain. It may be that they would like better quality data so that they can better stock inventory. Conversely, processors/traders/first handlers have a lot of data on expected yields and the current crop; however, yields can vary due to weather and other biological factors that make predicting output difficult. Thus, the data they have may be seen as a low-quality signal and is not useful data to the organization.

The heterogeneity in data collection continues when analyzing the survey responses by different job roles. Seventy-one percent of the respondents in an inbound logistics role indicated that their organization collects extensive data. The role with the second highest percentage of respondents that indicated their organization collects extensive data were those individuals in a procurement role. Procurement and inbound logistics are likely to be highly integrated for most agribusiness. However, outbound logistics had the lowest percentage of respondents indicating that their firm extensively collects data, with 23% of outbound logistic respondents indicating that their organization collects no data that is useful. The sales function was the second most negative role in terms of collecting data. Thirty-nine percent of respondents in a sales role said that their organization collects extensive data. However, a low percentage of respondents in a sales role indicated that their company collects no data.

The survey results by the role of respondent show that not only does data collection vary across the supply chain, but it can also vary within an organization. These results imply that companies collect data in areas they believe will have the highest impact. One role that should get particular attention is the outbound logistics role. One company's outbound logistics is connected to its customer's inbound logistics. Thus, this may be one bottleneck keeping data from freely flowing up and down the agricultural supply chain. While this does not necessarily mean that information on product outbound logistics is lost, it does imply that the business function responsible for moving product downstream has the least amount of data collection in the agricultural supply chain. On the surface, this may be explained by the fact that by the time the product has moved to the outbound logistics function, the product has already found a buyer at a given price, and the company sees little value in maintaining data beyond this point.

Level of data analysis

In the theme of companies' data collection and analytics, the respondents were asked what percentage of the decisions made in their companies were based on data analytics. The options were 0% (none), 1% to 25%, 26% to 50%, 51% to 75%, and 76% to 100%. The results for the level that data are used for decision-making for the different levels of the agricultural supply chain and by the respondent's role are in Table 3. The importance of understanding if data is being

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TABLE 3 Decisions made using data across agricultural supply chain and respondent role within organization.

Ag supply chain sector	0%	1% to 25%	26% to 50%	51% to 75%	76% to 100%
Overall	2.15%	14.26%	32.67%	36.25%	14.66%
Agricultural Input Manufacturer	0.55%	15.98%	28.37%	38.02%	17.08%
Agricultural Retailer / Dealer	1.73%	16.61%	35.99%	31.49%	14.19%
Processor / Trader / First Handler	2.26%	11.76%	38.91%	37.10%	9.95%
Food Manufacturer	2.86%	12.38%	31.90%	34.76%	18.10%
Food Retailer	5.23%	12.21%	29.07%	41.28%	12.21%
Respondent Role within Organization	**0%**	**1% to 25%**	**26% to 50%**	**51% to 75%**	**76% to 100%**
Executive or Upper Management	0.72%	8.51%	15.22%	15.58%	9.96%
Human Resource	0.94%	6.60%	17.92%	17.92%	6.60%
Inbound Logistics	2.08%	0.00%	14.58%	22.92%	10.42%
Marketing	0.29%	7.85%	16.57%	19.19%	6.10%
Operations	1.13%	7.63%	16.10%	16.38%	8.76%
Other	2.72%	7.61%	15.76%	16.30%	7.61%
Outbound Logistics	0.00%	6.45%	27.42%	14.52%	1.61%
Procurement	1.32%	7.89%	13.16%	18.42%	9.21%
Sales	1.33%	6.95%	16.57%	17.46%	7.69%
Service	2.55%	6.63%	8.16%	20.92%	11.73%

used to drive decision-making is exemplified when one considers that without the analytical capabilities to turn data into insights, acquiring more data is unlikely to have a significant impact within the food and agriculture sector (Sonka & Cheng, 2015). Analytics is what makes it possible for data to be transformed into knowledge, which in turn is used to acquire a competitive advantage through data-driven decision-making (Pham & Stack, 2018).

Overall, 51% of the respondents said that the majority of the decisions made (>51% of the decisions) were based on data analytics, reinforcing the perception of how important it is to be a data-driven company and also how this is embedded in these professionals' cultures. Only 2% of respondents indicated that their organization does not use data to make decisions. In total, 84% of the respondents indicated that over 25% of their companies' decisions are based on data. This reinforces the level to which agricultural companies are already using data and data analytics to improve profitability. Given that over half of the survey respondents believe that their company does not collect extensive data, this may hint at the current efforts underway in the agricultural supply chain to collect more data. Companies are realizing value from it as they use it to make decisions but would like more data to either make better decisions or to aid in decisions that are not currently driven by data (Table 4).

Examining the level of decision-making by level of the agricultural supply chain by those firms that make more than half of their decisions based on data, agricultural input manufacturers had the highest amount of decision-making from data. Fifty-five percent of agricultural input manufacturer respondents said that their firms make more than half of all decisions based on data. Agricultural input manufacturers have played a significant role in bringing digital platforms for data collection and analysis to the sector. Manufacturers have three of the most used

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TABLE 4 Mean ranking of important benefits of data analytics by levels of the supply chain.

	Agricultural input manufacturer	Agricultural retailer / dealer	Processor / trader / first handler	Food manufacturer	Food retailer	Average
Improved decision-making	1.88[a]	2.03[a]	2.48[a]	2.56[a]	2.43[a]	2.11[a]
Improved customer satisfaction	2.81[b]	2.57[b]	3.07[b]	2.89[b]	2.62[a]	2.91[b]
Improved operational efficiency	3.56[c]	3.28[c]	3.45[c]	3.41[c]	3.48[b]	3.43[c]
Driving company profitability	3.36[c]	3.44[c]	3.84[d]	3.64[c]	4.03[c]	3.57[c]
Improved market awareness	4.44[d]	4.58[d]	4.05[de]	4.54[d]	4.60[d]	4.41[d]
Improved compliance with data protection and privacy regulations	4.96[e]	5.00[e]	4.16[e]	4.04[e]	3.70[b]	4.57[e]

Note: Means with different superscripts in each column differ at the p = 0.05 level for the Conover test with the Bonferroni correction. As an example, because improved decision making has an "a" superscript, it is statistically different for the agricultural input manufacturer from any other option. Because both improved operational efficiency and driving company profitability have a "c" superscript, they are not statistically different from each other but are statistically different from all the other options in that collumn.

farm management software systems (Climate, JD center, and Case IH). The data created by these platforms, and other different primary sources, seems to be fueling decision-making in these companies, explaining not only these results but also the vast investment they have been making in data-related ventures (Agfunder, 2021; Burwood-Taylor, 2021; CB Insight, 2017).

Surprisingly, food retailers were next in using data to make decisions. These results of making decisions from data contrast the results of the firm's data collection, where food retailers had the lowest percentage of respondents, indicating that their firm collected extensive data among all levels of the agricultural supply chain. Thus, the level that had the perceived lowest amount of data collected indicated that they have the second highest percentage of their decisions based on data. This further indicates that the definition of data varies across the agricultural supply chain. It may also indicate that the value derived from data is different as well.

Agricultural input retailers had the lowest perception of data analytics usage for the majority of their decision-making (>51% of the decisions made), with 46%. One interesting point to note is that agricultural input retailers are the next level of the supply chain after the agricultural input manufacturers. This presents a significant difference in their perceptions of data analytics and its use in decision-making.

Examining data usage by respondent's role shows that agribusiness employees in inbound logistics and service roles believe that their organizations make the majority of their decisions based on data. Outbound logistics shows the lowest belief that their company uses data to make decisions most of the time. It may be surprising that survey respondents who are in an executive or upper management role did not believe that their organizations made a majority of their decisions based on data to a higher degree than many of the other roles within the

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organizations. Given executives' or upper management's purview, it may be logical to think that they see an aggregated form of data from across multiple other roles within the organization; however, this does not appear to be the case.

Data analytics benefits

To understand data analytics benefits, respondents were asked to rank the most important benefits of data analytics from 1 to 6, where 1 is the most important and 6 is the least important.

Improved decision-making was ranked as the most significant benefit for all levels of the agricultural supply chain. The ranking for improved decision-making was statistically different from the second-ranked choice for all levels of the supply chain except for food retailers. For food retailers, improved customer satisfaction, while ranked 2nd on average, was not statistically different from the first choice of improved decision-making. These results show that companies expect data to help them increase profitability by gaining insights into the company.

Food retailers being more undecided on the number one benefit is understandable since they are at the level of the agricultural supply chain that is selling products to the end consumer. They spend much time and energy attempting to understand the consumer better with surveys, tracking purchasing habits, and customer loyalty programs that log frequently bought items. These data help food retailers better market and target specific consumers to improve the customer experience.

Improved customer satisfaction had the second-highest average ranking for all levels of the agricultural supply chain. This result is in line with the idea that companies that are data-driven have the ability to not only better understand their customers' needs but also deliver on those needs more efficiently. Understanding customers' needs and preferences can be one of the hardest things a business can attempt to do since they are ever-changing. The existing data may be skewed for various reasons, such as biases, measurement errors, or omission of key variables.

The middle of the rankings has less agreement among the respondents. Improved operational efficiency and data-driving company profitability are ranked next for most levels of the agricultural supply chain. However, the statistical significance of the differences between the rankings is missing for most levels. First, respondents are less certain about some potential benefits that do not rise to the top of the rankings, and different levels of the agricultural supply chain have differences of opinion as to how beneficial each will be.

Improved compliance with data protection and privacy regulations had the lowest rank for agricultural input manufacturers, agricultural retailers, and processors/first handlers. Even though data protection and privacy issues are regarded as critical factors by farmers (Lioutas, Charatsari, La Rocca, & De Rosa, 2019; OECD, 2019) and agricultural businesses (World Bank, 2019) when considering adopting digital tools in their businesses, the survey respondents in the food and agricultural supply chain did not rank this as a significant benefit. The two levels of the supply chain closest to the consumer did not rank this option last but instead ranked it 5th (food manufacturer) and 4th (food retailer).

Given the results, it is possible to say that the food and agricultural supply chain has a clear vision of the most important benefits of data analytics, improved decision-making, and improved customer satisfaction and that there is a clear distinction between them. However, the respondents are less sure about the benefits after those top two.

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TABLE 5 Mean score of data-related challenges by levels of the supply chain.

	Agricultural input manufacturer	Agricultural retailer / dealer	Processor / trader / first handler	Food manufacturer	Food retailer	Average
Timeliness	8.25[a]	8.46[a]	7.99[a]	7.82[ab]	7.82[ab]	8.14[a]
Availability of data	8.00[a]	7.85[b]	7.75[ab]	7.99[a]	7.69[ab]	7.92[ab]
Talent and skills to collect and analyze data	7.80[ab]	8.05[ab]	7.64[ab]	7.87[ab]	7.75[ab]	7.85[b]
Security and privacy concerns	7.30[bc]	7.57[b]	7.51[ab]	7.66[ab]	8.21[a]	7.59[c]
Technology to collect and analyze data	7.21[cd]	7.49[b]	7.48[ab]	7.64[ab]	7.46[b]	7.45[c]
How data are struc tured	7.27[bcd]	7.37[bc]	7.42[ab]	7.55[ab]	7.44[b]	7.41[c]
Facilities and infrastructure to manage data	6.73[cd]	6.72[d]	7.35[ab]	7.33[ab]	7.36[b]	6.97[d]
Who owns the data	6.41[d]	6.76[d]	7.26[b]	7.26[b]	7.37[b]	6.94[d]
Cost of collecting and analyzing data	6.26[d]	6.91[cd]	7.31[ab]	7.19[b]	7.36[b]	6.94[d]
Volume	6.69[cd]	6.65[d]	7.09[b]	7.27[b]	7.55a[b]	6.93[d]

Note: Means with different superscripts in each column differ at the p = 0.05 level in Tukey HSD test. As an example, because timeliness has an "a" superscript and so does talent and skills to collect and analyze data for the agricultural input manufacturer, these barriers are not statistically different. Since how data are structured for the agricultural input manufacture has an "abc" superscript, it is not statistically different from any other barriers in the agricultural input manufacturer column that has any of those letters in the superscript.

Data-related challenges

Respondents were asked to rate the data-related challenges in their organizations on a scale from 1 to 10, where 1 meant not important, and 10 meant very important. Over the entire sample, timeliness had the highest score, followed by availability of data and talents and skills to collect and analyze data. Security and privacy concerns, technology to collect and analyze data, and how data are structured came next but had no statistical difference between them. Finally, the groups that presented the lowest scores were facilities and infrastructure to manage data, who owns the data, cost of collecting and analyzing data, and volume.

None of these were statistically different from each other (Table 5). It is important to note that even though there were statistical differences in the averages, all of them were in the upper third of the range (>6.6), which may indicate that the most significant barriers are well-known and universal. At the same time, respondents are not as sure about the extent the lower barrier may have on realizing value from data.

Comparatively, a survey conducted by the OCDE in 2019 showed that three challenges are perceived as the most critical limiting factors to data technologies in the agricultural sector: constrained financial resources, the necessary change to current workflows, policies, or programs, and access to specialized skills required to use "big data" (OECD, 2019).

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While the response in this survey for financial barriers was posed in a slightly different context, our respondents did not indicate cost as a significant barrier. Our survey corroborates the importance of overcoming the talent and skills needed to analyze the data.

Timeliness as the most critical challenge has several implications. First, agribusinesses are having issues collecting data and analyzing it in a quick enough time frame to be meaningful for the company. Companies either lack the proper resources to collect data or do not have the necessary skills to turn data into insights quickly enough to impact agribusiness. Also, the correlation between timeliness and the following two challenges should be emphasized.

Availability of data and the talent and skills to analyze may compound each other. The top three challenges show that human capital may be the main barrier to obtaining value from data rather than assets or technology. When considering the food and agricultural chain levels, agricultural dealers/retailers had the highest score for timeliness, indicating that this challenge is more prevalent at this level of the agricultural supply chain. Food manufacturers and food retailers were the only groups that did not score timeliness as the most critical challenge.

Food retailers had the highest score for security and privacy concerns, their most significant challenge, showing a clear distinction in their business model, in which this factor demands more attention. This result is further solidified when considering that the same group had the highest ranking for improved compliance with data protection and privacy regulations as a benefit of data analytics across all the levels in the supply chain. Consumers are concerned about how companies are using their data.

It should be noted that there is little to no statistical difference in the challenges for the downstream companies (food manufacturers and food retailers) in the agricultural supply chain. The upstream companies in the agricultural supply chain (agricultural input manufacturer and agricultural retailer/dealer) exhibit a clearer view of the main challenges related to data, while companies further downstream perceive these challenges more evenly among the options presented in this question.

CONCLUSIONS

This study employs data from a 2019 survey of agribusinesses across five different stages of the agricultural supply chain. We find that there is heterogeneity in the data collection efforts and analysis across the agricultural supply chain. This may be due to the agribusinesses having different definitions of what constitutes data. However, it is apparent that the level to which different levels of the agricultural supply chain use data at different rates.

The level to which agribusiness use data analytics to make decisions within their company is also heterogeneous. The level of decision-making from data analytics across the agricultural supply chain levels was not the same as the level of data collection. Put simply, collecting more data did not necessarily mean that a particular level of the agricultural supply chain made more decisions from data analytics.

Improved customer satisfaction and decision-making were the most important benefits of data collection. We also find that the expected benefits and barriers to implementing these efforts are not universal. Companies that exist upstream in the supply chain are more likely to disagree on intended benefits and challenges.

Timeliness, and talent and skills to collect and analyze data were two of the top three data-related challenges identified by survey respondents. Additionally, improved decision-making was perceived as the largest benefit. This highlights the need for investment into the human

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capital required to make progress in creating value. This also underscores the need for educational entities, at all levels to ensure that people form diverse backgrounds and education levels receive proper training in data analytic techniques.

While this research was not focused on any one policy, some of its outcomes are relevant for policymakers. First, there should be initiatives that can help agribusinesses to improve data collection and analysis timeliness. Access to rural broadband, technologies, and even other data sources, such as government data, can impact a company's ability to turn data into insights quickly and efficiently (OECD, 2019). Also, workforce development to train the next generation of agricultural workers and improve their talent and skills of data analysis will be crucial to ensure the agricultural supply has the talent pool it requires in the future (Eastwood et al., 2019).

Beyond that, the digitization of the agriculture and food industry has a very close relationship with policymaking. Advances in data collection technologies, advances in data processing, advances in encryption and data protection technologies, together with advances in institutions for data sharing offer the opportunity to broaden access and reduce the transaction costs of accessing agricultural and food data. These developments provide opportunities to improve policies by helping to overcome information gaps and asymmetries, lowering policy-related transaction costs and enabling people with different preferences and incentives to work better together (OECD, 2019).

ENDNOTES

[1] Because the distribution of job roles is not uniform across the various stages of the supply chain, this could drive any differences shown in the responses. This was checked for and found to not have any impact on the results.

[2] The Kruskal–Wallis test is defined as $H = \frac{(N-1)\left(\sum_{i=1}^{g} n_i(\bar{r}_i-\bar{r})^2\right)}{\sum_{i=1}^{g}\sum_{j=1}^{n_i}\left(r_{ij}-\bar{r}\right)^2}$, H is the Kruskal-Wallis test statistic, N is the total number of observation across all groups, g is the number of groups or ranking, n_i is the number of observations in group i, r_{ij} is the rank of observation j from group i, $\bar{r}_i$ is the average rank of all observations in group i, and $\bar{r}$, is the average of all r_{ij} (MacFarland & Yates, 2016).

[3] The post-hoc Conover test with Bonferroni correction is defined as $|R_k - R_j| \geq \sqrt{2\left(\frac{\sum_{i=1}^{n}\sum_{k=1}^{K} R_{ik}^2 - \sum_{k=1}^{K} R_k^2}{(n-1)(K-1)}\right)}$, where $|R_k - R_j|$ is the absolute value of the difference between the group means (Conover, 1999).

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