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RESEARCH ARTICLE

USDA Long-Term Meat Trade Projections: A Comprehensive Evaluation

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Abstract

The profitability of U.S. meat producers and the utility of U.S. meat consumers are impacted by the trade of meat. USDA publishes the most prominent publicly available meat trade projections. This study finds USDA projections typically underpredict meat export volumes and overpredict meat import volumes. USDA projections outperform naïve projections for beef and pork exports, but naïve projections at times outperform USDA projections for chicken exports and beef and pork imports, especially at shorter horizons. USDA projections exclude variety cuts, which comprise a sizeable share of beef and pork exports. There remains room for improvement in projecting U.S. meat trade.

Keywords: Beef; chicken; meat exports; meat imports; pork; projection accuracy; projection evaluation; USDA reports

JEL classifications: D84; Q13; Q17

1. Introduction

The U.S. is poised to continue to play a large role in supplying beef, pork, and chicken, among other proteins, to satisfy the growing global appetite for meat. The share of annual U.S. production of beef and pork that is exported continues to climb as is evidenced by Figure 1. Exports provide considerable value for U.S. meat producers. In 2021, beef and pork exports added an estimated value of $407.22 and $62.86 per head to U.S. fed cattle and hogs, respectively (USMEF, 2022a). Even though the share of production of chicken that is exported remains steady, chicken producers likewise benefit from export markets as the U.S. exported nearly 7.5 billion pounds of chicken in 2021. Furthermore, the U.S. oftentimes imports as much beef as it exports. While there exists economic justification for this activity, it nevertheless underscores the importance of meat trade flows both in and out of the country. Figure 2 graphs U.S. beef, pork, and chicken exports as well as beef and pork imports.

The United States Department of Agriculture (USDA) recognizes the importance of meat trade and aptly produces 10-year baseline projections for beef, pork, and chicken exports and beef and pork imports (OCE, 2022). The U.S. imports only a small amount of chicken, so USDA does not include chicken imports in their annual long-term projections. Baseline numbers are frequently used by policymakers, industry participants, and producers to garner insights on the future of agriculture in the U.S. Their impact is far-reaching in that they are often used to evaluate the feasibility of agricultural policies and quantify impacts of various shock scenarios that could disrupt agricultural markets in the U.S.

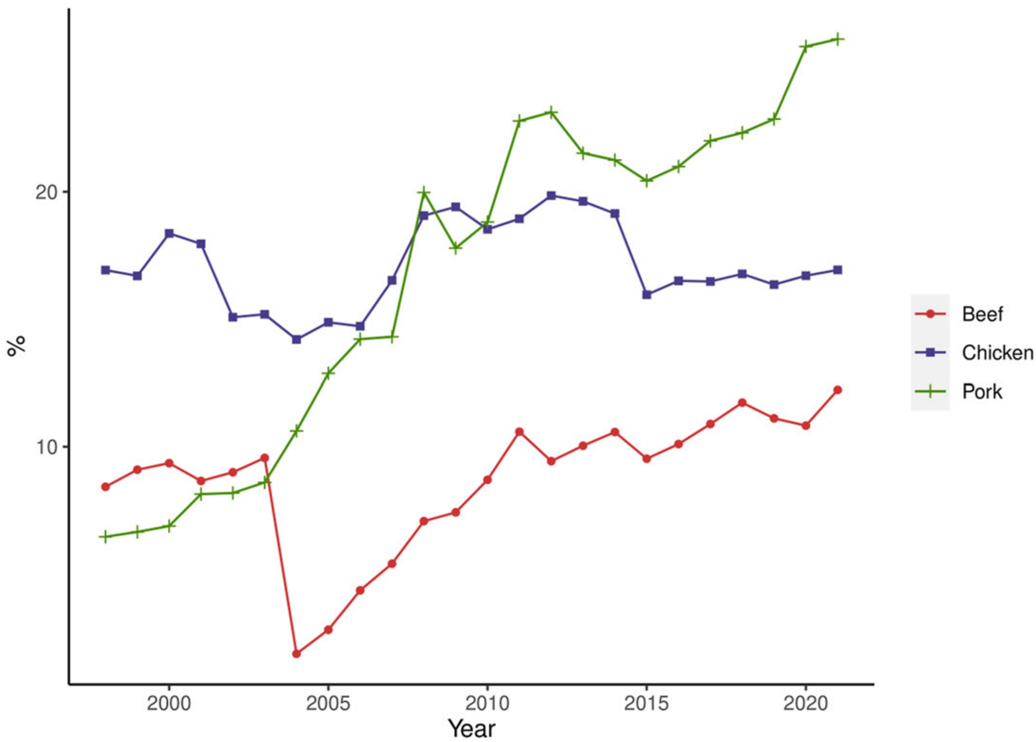

Figure 1. Percentage share of U.S. beef, chicken, and pork production exported annually.

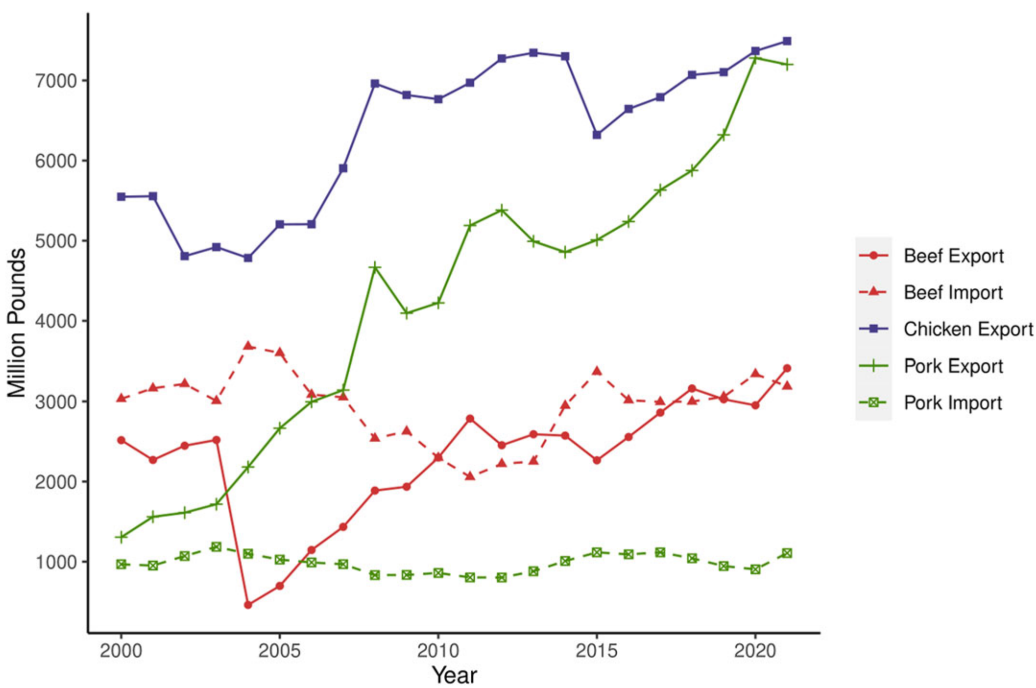

Figure 2. U.S. meat export and import volumes.

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The purpose of this paper is to assess the accuracy, optimality, and informativeness of USDA projections for U.S. meat exports and imports.[1] Optimality refers to both unbiasedness and efficiency of the projections. We compare USDA projections to naïve, no change projections. That is, naïve projections assume the most recently observed outcome remains constant for the next ten years of projections. We ultimately seek to provide better understanding of the usability of these projections in decision making for stakeholders in the U.S. meat-livestock sector as well as provide suggestions to the USDA on potential methods to improve the projections going forward.

There exists a great volume of research evaluating other forecasts and projections produced by USDA, including crop production (Baur and Orazem, 1994; Bora, Katchova, and Kuethe, 2022; Egelkraut et al., 2003; Isengildina, Irwin, and Good, 2006, 2013; Isengildina-Massa, Karali, and Irwin, 2020; Isengildina-Massa, MacDonald, and Xie, 2012; Lewis and Manfredo, 2012), crop prices (Elam and Holder, 1985), grain ending stocks (Xiao, Hart, and Lence, 2017), livestock production (Bailey and Brorsen, 1998; Sanders and Manfredo, 2002), and livestock prices (Kastens, Schroeder, and Plain, 1998; Sanders and Manfredo, 2003). Additionally, there are various works that look at USDA farm economy indicators such as net farm income (Isengildina-Massa et al., 2021; Kuethe et al., 2018) and net cash income (Bora, Katchova, and Kuethe, 2021; Isengildina-Massa et al., 2020; Kuethe, Bora, and Katchova, 2022).

Many of these studies follow similar approaches. Isengildina, Irwin, and Good (2013), for example, utilize efficiency tests to find that corn and soybean yield forecasts typically incorporate available information efficiently. That is, it is difficult to anticipate at the time crop size forecast revisions that may look obvious in hindsight. Recent work by Bora, Katchova, and Kuethe (2022) analyzes the accuracy and informativeness of USDA baseline projections for three major commodities (corn, soybeans, and wheat) and net cash income. The study finds that prediction error and bias in projections increases as the length of the projection horizon increases and that baselines are rarely informative more than 4–5 years out.

Using similar methodology to these studies, we complete a comprehensive evaluation focused on USDA baseline projections for meat exports and imports. We first provide an overview of the baseline projection process and specific data used. Projection evaluation methods are then outlined followed by empirical results. Finally, the paper is concluded with a discussion of key takeaways and suggestions for future work in this space.

2. Data

Each February, the United States Department of Agriculture (USDA) releases the USDA Agricultural Projections report. This report encompasses long-term baseline projections for U.S. agriculture and includes baseline numbers that "… provide a starting point for discussion of alternative outcomes for the sector" over the coming decade (USDA OCE, 2022). Agricultural commodities, agricultural trade, and aggregate economic indicators such as farm income are all covered and discussed in detail in USDA long-term projections. This study focuses specifically on USDA meat trade projections, including beef, pork, and chicken exports and beef and pork imports. Historic projections are archived and were retrieved from the Albert R. Mann Library, at Cornell University. USDA stresses that these projections are not meant to forecast the future but rather provide what would be expected in the agricultural sector based on specific assumptions including status quo macroeconomic conditions, agricultural and trade policies, and growth rates of agricultural productivity both in the U.S. and internationally. The projections do not consider any potential shocks that could impact global agricultural supply and demand.

USDA Agricultural Projections report is the result of the efforts of many interagency committees within USDA, but the Economic Research Service (ERS) takes the lead role. The projections

[1]Throughout the paper, we use the term "projection" rather than "forecast" to remain consistent with the terminology used in annually published USDA Agricultural Projections.

Table 1. USDA long-term pork imports projection process, million pounds

Projection Year, t	Report Release Date												
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2019	$P_{2019,t\text{-}9}$	$P_{2019,t\text{-}8}$	$P_{2019,t\text{-}7}$	$P_{2019,t\text{-}6}$	$P_{2019,t\text{-}5}$	$P_{2019,t\text{-}4}$	$P_{2019,t\text{-}3}$	$P_{2019,t\text{-}2}$	$P_{2019,t\text{-}1}$	$P_{2019,t\text{-}0}$		A_{2019}	
	1201	1080	1060	894	925	939	1035	1040	1032	1060	956	945	
2020		$P_{2020,t\text{-}9}$	$P_{2020,t\text{-}8}$	$P_{2020,t\text{-}7}$	$P_{2020,t\text{-}6}$	$P_{2020,t\text{-}5}$	$P_{2020,t\text{-}4}$	$P_{2020,t\text{-}3}$	$P_{2020,t\text{-}2}$	$P_{2020,t\text{-}1}$	$P_{2020,t\text{-}0}$		A_{2020}
		1105	1085	908	938	952	1045	1058	1038	1070	915	871	904

Notes: To clarify, the projection for 2019 at horizon $h = 9$ was included in the 2010 baseline, at horizon $h = 8$ in the 2011 baseline, and so on. A_{2019} (the actual volume for 2019) was released two years after 2019 in the 2021 baseline. Projections for 2020 follow a parallel pattern.

are based on composite model results as well as judgment-based analyses and reflect the knowledge and expertise of numerous individuals and entities within USDA. ERS maintains multiple partial equilibrium models that use economic behavioral relationships to produce projections (Hjort et al., 2018). In August and September of the year prior to the report's release date, ERS begins outlining the macroeconomic assumptions that will be included in generating the projections. Throughout the following months, committees examine various parts of the U.S. agricultural sector to best represent the current situation. USDA uses data from the October or November World Agricultural Supply and Demand Estimates (WASDE) report in its calculations, and projections are put together in January. Ultimately, they are cleared by the World Agricultural Outlook Board and released from the Office of the Chief Economist in February (USDA OCE, 2022).

This paper focuses on meat trade projections measured in million pounds. These are annual projections of a terminal event (t), which is the realized trade volume of a specific commodity for a specific year. They are also multihorizon "path" projections because a sequence of projections is made simultaneously for multiple terminal events in the future. That is, t is predicted annually at horizon (h). Because the final projection is released in February of the year it is projecting, $h = 0, \ldots, 9$. We define $P_{t,t-h}$ as the projection for t at horizon h. Because ten-year projections began in 1998, projections for meat exports and imports in 2007 through 2021 are analyzed as 2007 was the first year to have a full ten years of projections leading up to it. Along with projections for the future, USDA baselines additionally include volumes for one and two years prior to the first projection year in each release. That is, for example, the 2022 baseline included projections for 2022 through 2031 as well as retrospective volumes for 2020 and 2021. The volume included for two years prior to the first projection year in each release is used as the actual (A_t) realized volume in our analysis.[2] Thus, the 2020 value included in the projections released in 2022 is used as the actual volume for 2020. Table 1 outlines the projection and revision process for pork imports for years 2019 and 2020.

Figure 3 illustrates the projected baseline volumes versus the realized volumes for beef exports. This series is an interesting example because of bovine spongiform encephalopathy (BSE) that occurred in the U.S. in December 2003, causing detriment to U.S. beef exports in the following years. The extreme decrease in beef exports in 2004 was not anticipated as is shown by the

[2]This is the case for all years except 2021. A_{2021} volumes were retrieved from USDA Agricultural Projections to 2031 (released February 2022) due to the February 2023 projections having not yet been released.

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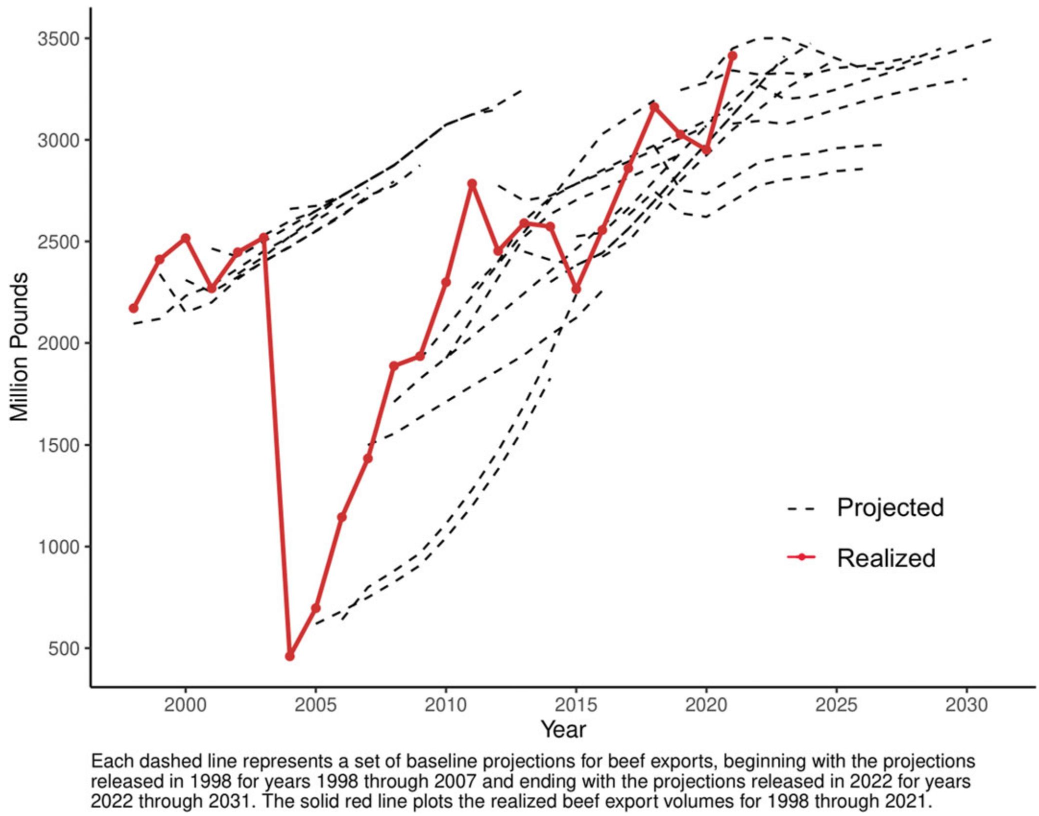

Figure 3. USDA projected baseline and realized volumes for beef exports.

difference between the actual export volume and the volumes projected for 2004 in the years leading up to the event. Yet projections created in 2005 and 2006 take into account the new market information and are strikingly lower as a result. It is also shown that from outside of this isolated event, projections and actual values do not tend to be always higher or lower than the actual volumes and that projections have largely predicted the increasing export trend occurring in the U.S. beef market.

Likewise, naïve projections used in this analysis assume the most recently observed outcome remains constant for the next 10 years of projections. For example, the realized beef export volume in 1998 is "projected" to be the beef export volume for 1999 through 2008. Stated differently, the realized beef export volume in 1998 is the $h = 0$ projection for 1999, the $h = 1$ projection for 2000, the $h = 2$ projection for 2001, and so on through the $h = 9$ projection in 2008. However, in the following year (i.e. 1999), the realized export volume would be the $h = 0$ projection for 2000, and $h = 1$ projection for 2001 and so on through the $h = 9$ projection for 2009. Table 2 provides a summary of descriptive statistics for both USDA and naïve projections as well as the actual export and import volumes as reported by USDA. Mean projected volumes for beef, chicken, and pork exports as well as pork imports generated by USDA are typically greater than naïve projections. Mean projections for beef imports are mixed between USDA and naïve being greater. Both USDA and naïve projections for pork exports seem to underpredict actual values. Conversely, USDA projections for pork imports appear to overpredict actual values in many periods.

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Table 2. Descriptive statistics of USDA and naïve projections for 2007–2021, million pounds

		Beef Export			Chicken Export			Pork Export			Beef Import			Pork Import		
		Mean	SD	Actual	Mean	SD	Actual	Mean	SD	Actual	Mean	SD	Actual	Mean	SD	Actual
2007	USDA	2,245	826	1,434	5,969	615	5,904	2,067	477	3,141	3,073	420	3,052	1,010	271	968
	Naïve	1,877	753		5,028	316		1,759	617		3,064	379		945	166	
2008	USDA	2,204	824	1,887	5,919	527	6,961	2,245	572	4,667	3,110	348	2,538	1,072	227	832
	Naïve	1,807	759		5,152	385		1,969	691		3,135	294		979	129	
2009	USDA	2,203	812	1,935	5,985	503	6,818	2,566	857	4,095	3,052	347	2,626	1,108	209	834
	Naïve	1,779	750		5,381	633		2,313	1,016		3,125	313		991	106	
2010	USDA	2,210	774	2,299	6,029	5185	6,765	2,864	1,001	4,224	3,021	315	2,297	1,142	192	859
	Naïve	1,731	723		5,570	741		2,594	1,079		3,100	341		992	105	
2011	USDA	2,230	679	2,785	6,109	538	6,971	3,219	1,083	5,189	2,983	339	2,057	1,155	197	803
	Naïve	1,709	702		5,692	823		2,886	1,086		3,026	418		981	112	
2012	USDA	2,307	590	2,453	6,095	340	7,274	3,595	1,127	5,381	2,944	417	2,220	1,148	229	802
	Naïve	1,761	758		5,834	905		3,249	1,184		2,916	504		967	124	
2013	USDA	2,354	476	2,590	6,252	421	7,645	4,011	1,115	4,992	2,976	370	2,250	1,117	250	880
	Naïve	1,761	758		6,081	927		3,626	1,203		2,816	533		940	128	
2014	USDA	2,366	319	2,573	6,464	533	7,301	4,405	987	4,857	3,022	372	2,947	1,065	177	1,008
	Naïve	1,769	766		6,323	909		3,953	1,078		2,740	553		909	99	
2015	USDA	2,526	239	2,265	6,698	551	6,321	4,755	828	5,009	3,053	361	3,371	1,034	134	1,116
	Naïve	1,980	659		6,575	789		4,221	927		2,667	466		900	84	
2016	USDA	2,616	230	2,556	6,862	557	6,644	5,058	651	5,239	3,083	367	3,015	1,029	124	1,091
	Naïve	2,137	504		6,687	654		4,455	790		2,644	423		909	100	
2017	USDA	2,734	184	2,860	7,048	551	6,791	5,339	427	5,632	3,027	359	2,993	1,035	113	1,116
	Naïve	2,278	392		6,830	433		4,679	650		2,637	417		919	112	

(*Continued*)

Table 2. (*Continued*)

		Beef Export			Chicken Export			Pork Export			Beef Import			Pork Import		
		Mean	SD	Actual	Mean	SD	Actual	Mean	SD	Actual	Mean	SD	Actual	Mean	SD	Actual
2018	USDA	2,855	160	3,161	7,240	518	7,069	5,588	229	5,876	2,996	224	2,998	1,019	95	1,042
	Naïve	2,420	309		6,919	307		4,929	462		2,631	411		934	126	
2019	USDA	2,903	160	3,026	7,408	485	7,103	5,779	254	6,321	3,024	217	3,058	1,027	84	945
	Naïve	2,548	325		6,930	310		5,049	531		2,677	424		955	125	
2020	USDA	3,007	203	2,951	7,589	425	7,367	6,074	466	7,280	3,018	207	3,342	1,011	71	904
	Naïve	2,657	282		6,958	312		5,272	551		2,721	438		966	119	
2021	USDA	3,103	210	3,414	7,720	382	7,491	6,379	657	7,199	3,035	206	3,187	1,008	66	1,107
	Naïve	2,717	262		7,007	315		5,584	726		2,836	462		967	118	
Count:																
Mean USDA > Actual				6			8			0			9			10
Mean USDA < Actual				9			7			15			6			5
Mean Naïve > Actual				1			3			0			7			8
Mean Naïve < Actual				14			12			15			8			7

Note: Means are calculated using 10 projections for each category (i.e., beef export, chicken export, etc.) for each year.

3. Methods

An optimal projection should become more accurate as the terminal event draws nearer. That is, as the projection horizon decreases, the projection error should likewise decrease (Patton and Timmerman, 2007). Both mean absolute percent error (MAPE) and root mean squared percent error (RMSPE) are used to measure accuracy following equations (1) and (2), respectively, where the observation period is $t = 2007, \ldots, 2021$ and h denotes horizons $h = 0, \ldots, 9$. The sample size for each horizon is $T = 15$.

$$\text{MAPE}_h\text{: } 100 \times \frac{\sum_{t=2007}^{2021} |\ln A_t - \ln P_{t,t-h}|}{\text{T}} \tag{1}$$

$$\text{RMSPE}_h\text{: } 100 \times \sqrt{\frac{\sum_{t=2007}^{2021} (\ln A_t - \ln P_{t,t-h})^2}{\text{T}}} \tag{2}$$

MAPE measures the average absolute projection error, whereas RMSPE measures the average squared projection error over the observation period. MAPE puts less weight on large projection errors than RMSPE. Thus, minimizing MAPE results in projection errors that are on average close to 0 over the timeframe, but minimizing RMSPE results in fewer projection errors with sizeable deviations from 0 over the timeframe. Both MAPE and RMSPE should decline as the projection horizon shortens and t approaches. These measures are horizon specific.

An optimal projection is also both unbiased and efficient (Diebold and Lopez, 1996). A projection is considered unbiased if there is no systematic difference from its realized values. It is efficient when it contains all available information at the time of the projection and is independent of previous projection revisions. Multiple empirical tests exist to evaluate the bias and efficiency of projections. To determine optimality, we follow the methodology of similar studies that address USDA forecasts, including Isengildina, Irwin, and Good (2013), Lewis and Manfredo (2012), and Kuethe et al. (2018) among others.

Holden and Peel (1990) proposed a bias test outlined in equation (3):

$$\ln A_t - \ln P_{t,t-h} = \alpha + \varepsilon_{t,t-h} \tag{3}$$

where t-h is the projection horizon, t is the year of the terminal event, and h is the number of periods preceding the terminal event. The projection error is measured as $\ln A_t - \ln P_{t,t\text{-}h}$, where $\ln A_t$ is the natural logarithm of the actual, realized volume of exports or imports at year t and $\ln P_{t,t\text{-}h}$ is the natural logarithm of the projection for year t at horizon h. Natural logarithms are used to be able to analyze results in percentage terms, which allows for easier comparison between imports and exports and across proteins. This and subsequent projection optimality equations are estimated via OLS and assume symmetric loss functions. Newey and West (1987) heteroskedasticity and autocorrelation consistent (HAC) standard errors are used in this analysis to address heteroskedasticity caused by decreasing variance of projections as the horizon becomes shorter and autocorrelation stemming from the overlapping nature of the projections.

Unbiasedness is tested with the null hypothesis H_0: $\alpha = 0$. Rejecting the null hypothesis indicates that systematic bias exists within the projections. If α is negative and statistically significant ($\ln A_t < \ln P_{t,t\text{-}h}$), this suggests that the projections systematically overpredict the actual volume of exports or imports of the commodity. On the other hand, if α is positive and statistically significant ($\ln A_t > \ln P_{t,t\text{-}h}$), the projections systematically underpredict the realized volume. Like MAPE and RMSPE, bias tests are also horizon specific.

Efficient projections encompass all available information and should be independent of previous projection revisions. While numerous studies in the literature utilize efficiency tests developed by Nordhaus (1987), these tests are not well-suited for multihorizon projections and possess limited power in assessing finite samples. Thus, following similar work by Kuethe et al. (2018), we employ an efficiency testing framework for multihorizon projections developed by Patton and Timmermann (2012), which has greater power to discover inefficiency in finite samples. This test asserts that actual, realized volumes should be perfectly, positively correlated with the final projection (at $h = 0$) and uncorrelated with previous projection revisions. Specifically, we estimate equation (4):

$$\ln A_t = \alpha + \beta_0 \ln P_{t,t-0} + \sum_{h=0}^{8} \gamma_h (\ln P_{t,t-h} - \ln P_{t,t-(h+1)}) + \varepsilon_t \tag{4}$$

where $t - (h + 1)$ is the time horizon of the previous projection, conducted 1 year prior to the projection at horizon h. That is, the actual, realized volume at time t is regressed on the projection made at the shortest horizon $h = 0$ and all preceding projection revisions. The joint null hypothesis is tested on the restriction H_0: $(\alpha, \beta_0) = (0, 1) \cap \gamma_h = 0$ for $h = 0, \ldots, 8$. Rejecting the null hypothesis suggests inefficiency in the projections. Failing to reject the null hypothesis suggests projections are efficient.

We determine the maximum informative projection horizon by comparing the projections' mean-squared prediction errors to the variance of the evaluation sample as proposed by Breitung and Knüppel (2021). The Breitung and Knüppel test states that the ideal projection equals the conditional expectation $\mu_{h,t} = E(P_{t,t-h}|I_{t-h})$ under quadratic loss, where $P_{t,t-h}$ is the projection for year t at horizon h and I_{t-h} is defined as the information set available at time $t - h$. It relies on the assumption that the realized trade volumes, A_t, are generated by a stationary and ergodic stochastic process. The Breitung and Knüppel test is favorable in that it circumvents the need to compare projections to naïve benchmarks and instead compares prediction errors to the variance of realized values.

Two sets of hypotheses are tested. First, the *no information* hypothesis seeks to determine if a maximum projection horizon, h^*, exists where beyond that point A_t is unpredictable with the given information set. The null hypothesis and alternative are

$$H_0: E(A_t - P_{t,t-h})^2 \geq E(A_t - \mu)^2 \text{ for } h > h^* \tag{5a}$$

$$H_1: E(A_t - P_{t,t-h})^2 < E(A_t - \mu)^2 \tag{5b}$$

where $\mu = E(A_t)$ is the unconditional mean of the actual realized trade volumes. Second, the *constant mean* hypothesis tests if the conditional expectation of the projection is constant within the sample. Its null and alternative are

$$H_0: E(P_{t,t-h}|I_{t-h}) = \mu_{h,t} = \mu, \text{ for } h > h^* \tag{6a}$$

$$H_1: E(P_{t,t-h}|I_{t-h}) \neq \mu_{h,t} = \mu. \tag{6b}$$

To empirically test these hypotheses, Breitung and Knüppel (2021) first focus on three potential scenarios for how projections are developed. The first two scenarios are based on survey expectations derived from individuals. The first assumes the projections are equal to a conditional mean function whereas the second assumes projections involve some additional noise. Finally, the third scenario assumes the projections are generated from an estimated model. We focus on the second and third scenarios based on the USDA baseline projection generation process discussed previously wherein both economic models and individuals' expectations shape the projected values. This follows the approach of Bora, Katchova, and Kuethe (2022), which evaluated grain and oilseed markets and farm income baseline projections developed by USDA in a similar way.

Scenarios two and three allow both sets of hypotheses to be tested using coefficients from Mincer-Zarnowitz regressions estimated via OLS (Mincer and Zarnowitz, 1969). It is shown in Breitung and Knüppel (2021) that if projections are generated by a conditional mean and noise (η_t), that is $P_{t,t-h} = \mu_{h,t} + \eta_t$, then the *no information* hypothesis is equivalent to testing the null hypothesis that $\beta_h \leq 0.5$ in the regression:

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$$A_t = \beta_{0,h} + \beta_h P_{t,t-h} + \nu_{t-h}. \tag{7}$$

The *constant mean* hypothesis is equivalent to testing the null hypothesis that $\beta_h \leq 0$ in the same regression equation. The β_h parameters can be tested using a HAC t-statistic:

$$\tau_a = \frac{1}{\widehat{\omega_a}\sqrt{T}} \sum_{t=1}^{T} a_t \tag{8}$$

where $\hat{\omega_a}^2$ is a consistent estimator for the long-run variance of a_t. The form of a_t varies based on the specific null hypothesis:

$$a_t = [A_t - \overline{A}_t - 0.5(P_{t,t-h} - \overline{P}_{t,t-h})](P_{t,t-h} - \overline{P}_{t,t-h}) \quad \text{for} \quad H_0\colon \beta_h = 0.5 \tag{9}$$

$$a_t = (A_t - \overline{A}_t)(P_{t,t-h} - \overline{P}_{t,t-h}) \quad \text{for} \quad H_0\colon \beta_h = 0. \tag{10}$$

The in-sample mean of the projections is used in calculating the HAC t-statistic rather than the recursive mean, which would require an expanding sample. Breitung and Knüppel (2021) find that the test using an in-sample mean, which is simpler and requires fewer assumptions than the recursive mean alternative, tends to perform better in many cases. The maximum informative horizon, h^*, is determined by sequentially testing the hypotheses starting at $h = 0, 1, 2, \ldots$ until they cannot be rejected for the first time. Then h^* is the penultimate horizon tested. The *no information* hypothesis is a more conservative test than the *constant mean* hypothesis. Results for both will be discussed.

Finally, we compare USDA and naïve projections at each projection horizon. The Diebold-Mariano test, defined in equation (11), is often used for this purpose:

$$\text{DM} = \overline{d_t} \cdot \left[\hat{V}(\overline{d_t})\right]^{-\frac{1}{2}} \tag{11}$$

where $d_t = |\ln A_t – \ln P_{t,t-h}{}^N| - |\ln A_t – \ln P_{t,t-h}{}^U|$ and superscripts N and U refer to naïve and USDA projections, respectively. That is, the absolute value of the error for USDA projections is subtracted from the absolute value of the error for naïve projections. Furthermore, $\overline{d_t}$ is the average d_t, and T is the number of observations. $\hat{V}$ is the estimated variance of $\overline{d_t}$ as defined by Diebold and Mariano (1995). The Diebold-Mariano test tends to reject the null hypothesis too frequently when the sample size is small. Therefore, we employ a modified Diebold-Mariano (MDM) test outlined in Harvey, Leybourne, and Newbold (1997), which determines if the difference between the mean absolute errors of USDA projections and naïve projections is different from 0 while taking into account the sample size and projection horizon (h). Equation (12) outlines this modification of equation (11):

$$\text{MDM} = \sqrt{\frac{T + 1 - 2h + h(h-1)/T}{T}}\text{DM}. \tag{12}$$

The sample size is $T = 15$. The MDM test statistic follows a t-distribution with T-1 degrees of freedom. If the difference is negative and statistically significant, this suggests that naïve projection errors are significantly smaller than USDA projection errors. A positive and statistically significant difference indicates that naïve projection errors are significantly larger than USDA projection errors.

4. Results

Mean absolute percent errors (MAPE) for meat export and import projections are displayed in Table 3 as well as Figure 4. As previously stated, the optimal projection should become more

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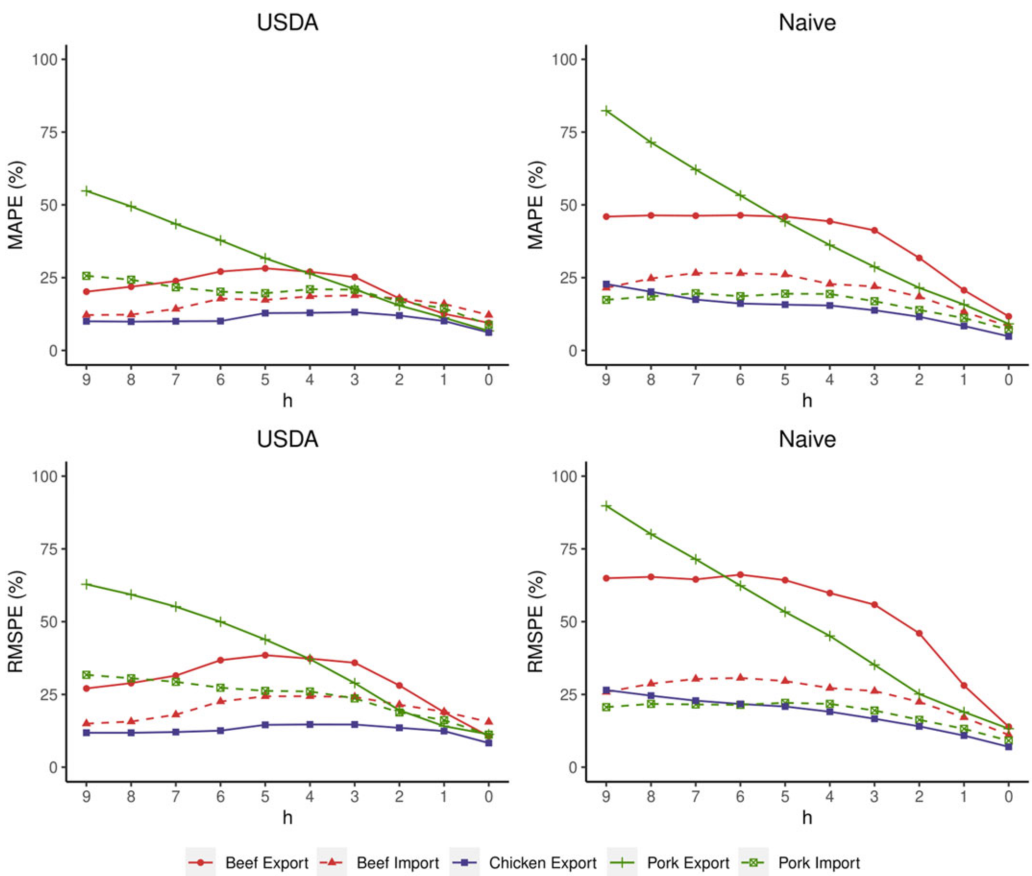

Figure 4. MAPE and RMSPE for USDA and naïve projections.

accurate as the horizon decreases. This clearly holds for both USDA and naïve pork export projections. According to Table 3, the MAPE for USDA pork export projections is 55% when projecting from horizon $h = 9$ but only about 7% at horizon $h = 0$. However, the same downward trend is not as clear in other cases. For example, projection errors for beef exports and imports from USDA peak at horizons $h = 5$ and $h = 4$, respectively. On balance, Figure 4 reveals that errors for beef and pork export projections by USDA are notably smaller than those of naïve expectations, but errors for chicken exports, beef imports, and pork imports seem to be fairly similar between USDA and naïve projections. Additionally, while MAPE for all projections at horizon $h = 0$ are in the range of 5 to 12%, both USDA and naïve projections of pork exports at the longest horizon have the greatest MAPE followed by beef exports as compared to the others.

Similar to MAPE, the measures of RMSPE should decline as the terminal event draws nearer. Table 4 and Figure 4 again summarize RMSPE, and present similar takeaways as discussed above. One should note, however, that while RMSPE are higher than MAPE across the board, there is a considerable difference between the two for beef exports. Likely, this is due to the BSE event that was alluded to previously. Because RMSPE places greater weight on projection errors that deviate further from 0, projections that were made before BSE (and therefore overpredicted the actual volume of U.S. beef exports in the years post-BSE) would cause the RMSPE value to be greater in magnitude than MAPE relative to similar comparisons that can be made for the other proteins.

Results of bias testing are reported in Table 5. USDA projections systematically underpredict beef export volumes at horizons $h = 1$ and $h = 2$ by 10% and 16%, respectively. The bias

Table 3. MAPE accuracy test

	$h = 9$	$h = 8$	$h = 7$	$h = 6$	$h = 5$	$h = 4$	$h = 3$	$h = 2$	$h = 1$	$h = 0$
USDA Exports										
Beef	0.20	0.22	0.24	0.27	0.28	0.27	0.25	0.18	0.13	0.10
Chicken	0.10	0.10	0.10	0.10	0.13	0.13	0.13	0.12	0.10	0.06
Pork	0.55	0.50	0.43	0.38	0.32	0.26	0.21	0.15	0.11	0.07
Naïve Exports										
Beef	0.46	0.46	0.46	0.46	0.46	0.44	0.41	0.32	0.21	0.12
Chicken	0.23	0.20	0.18	0.16	0.16	0.15	0.14	0.12	0.08	0.05
Pork	0.82	0.71	0.62	0.53	0.44	0.36	0.29	0.22	0.16	0.09
USDA Imports										
Beef	0.12	0.12	0.14	0.18	0.17	0.19	0.19	0.18	0.16	0.12
Pork	0.26	0.24	0.22	0.20	0.20	0.21	0.21	0.17	0.14	0.09
Naïve Imports										
Beef	0.22	0.25	0.27	0.27	0.26	0.23	0.22	0.19	0.13	0.09
Pork	0.17	0.19	0.20	0.19	0.20	0.19	0.17	0.14	0.11	0.07

Note: h denotes the projection horizon.

Table 4. RMSPE accuracy test

	$h = 9$	$h = 8$	$h = 7$	$h = 6$	$h = 5$	$h = 4$	$h = 3$	$h = 2$	$h = 1$	$h = 0$
USDA Exports										
Beef	0.27	0.29	0.32	0.37	0.39	0.37	0.36	0.28	0.19	0.11
Chicken	0.12	0.12	0.12	0.13	0.15	0.15	0.15	0.14	0.12	0.08
Pork	0.63	0.59	0.55	0.50	0.44	0.37	0.29	0.20	0.14	0.11
Naïve Exports										
Beef	0.65	0.65	0.65	0.66	0.64	0.60	0.56	0.46	0.28	0.14
Chicken	0.27	0.25	0.23	0.22	0.21	0.19	0.17	0.14	0.11	0.07
Pork	0.90	0.80	0.71	0.62	0.53	0.45	0.35	0.25	0.19	0.13
USDA Imports										
Beef	0.15	0.16	0.18	0.23	0.24	0.24	0.24	0.26	0.19	0.16
Pork	0.32	0.31	0.29	0.27	0.26	0.26	0.24	0.19	0.16	0.11
Naïve Imports										
Beef	0.26	0.29	0.30	0.31	0.30	0.27	0.26	0.22	0.17	0.11
Pork	0.21	0.22	0.22	0.21	0.22	0.22	0.20	0.16	0.13	0.10

Note: h denotes the projection horizon.

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Table 5. Holden and Peel (1990) bias test

	$h = 9$	$h = 8$	$h = 7$	$h = 6$	$h = 5$	$h = 4$	$h = 3$	$h = 2$	$h = 1$	$h = 0$
USDA Exports										
Beef	−0.12	−0.08	−0.05	−0.02	0.03	0.08	0.13	0.16*	0.10*	0.03
	(0.08)	(0.09)	(0.10)	(0.12)	(0.12)	(0.12)	(0.09)	(0.08)	(0.05)	(0.02)
Chicken	0.07**	0.07**	0.07*	0.05	0.05	0.05	0.05	0.05	0.04	0.03
	(0.03)	(0.03)	(0.03)	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.03)
Pork	0.55***	0.49***	0.43***	0.38***	0.31***	0.25**	0.18**	0.12**	0.05	0.02
	(0.11)	(0.12)	(0.12)	(0.12)	(0.11)	(0.10)	(0.08)	(0.05)	(0.04)	(0.03)
Naïve Exports										
Beef	0.35*	0.34*	0.32*	0.32*	0.33*	0.32*	0.31**	0.29**	0.17**	0.07**
	(0.18)	(0.18)	(0.19)	(0.19)	(0.18)	(0.16)	(0.13)	(0.12)	(0.07)	(0.03)
Chicken	0.23***	0.20***	0.17***	0.14**	0.13**	0.12**	0.10*	0.07*	0.05	0.02
	(0.05)	(0.05)	(0.06)	(0.06)	(0.06)	(0.05)	(0.05)	(0.04)	(0.03)	(0.02)
Pork	0.82***	0.71***	0.62***	0.53***	0.44***	0.36***	0.28***	0.20***	0.13***	0.06**
	(0.13)	(0.13)	(0.13)	(0.12)	(0.11)	(0.09)	(0.07)	(0.05)	(0.04)	(0.03)
USDA Imports										
Beef	−0.07*	−0.10**	−0.11*	−0.11	−0.12	−0.11	−0.10	−0.09	−0.04	−0.01
	(0.04)	(0.04)	(0.05)	(0.07)	(0.07)	(0.08)	(0.08)	(0.07)	(0.06)	(0.04)
Pork	−0.14	−0.16*	−0.17*	−0.16*	−0.14*	−0.12	−0.10	−0.06	−0.01	0.02
	(0.10)	(0.09)	(0.08)	(0.08)	(0.08)	(0.08)	(0.08)	(0.06)	(0.05)	(0.04)
Naïve Imports										
Beef	−0.03	−0.03	−0.01	−0.02	−0.02	−0.02	−0.02	−0.02	0.00	0.00
	(0.09)	(0.10)	(0.11)	(0.11)	(0.11)	(0.10)	(0.10)	(0.08)	(0.06)	(0.03)
Pork	0.05	0.03	0.01	0.00	−0.01	−0.02	−0.02	−0.01	0.00	0.00
	(0.07)	(0.07)	(0.08)	(0.08)	(0.08)	(0.08)	(0.07)	(0.06)	(0.04)	(0.03)

Notes: h denotes the projection horizon. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level, respectively. Independent variable is projection error ($\ln A_t - \ln P_{t,t\text{-}h}$). Dependent variable is intercept of Holden and Peel (1990) regressions. Heteroskedasticity and autocorrelation consistent (HAC) standard errors are in parentheses (Newey and West, 1987).

coefficients on USDA chicken export projections at $h = 7$ through $h = 9$ suggest underprediction by 7%. USDA projections for pork exports are biased and underpredicted for nearly every horizon, excluding the two horizons closest to the terminal event. Further, these biases range from 12% to a striking 55%. Looking at imports, USDA systematically overpredicts beef imports at horizons $h = 7$ through $h = 9$ and pork imports at horizons $h = 5$ through $h = 8$.

The results suggest that there is a dichotomy between USDA projections of meat exports relative to imports in that USDA export projections tend to underpredict, while USDA import projections tend to overpredict. In essence, USDA projections systematically conjecture that less beef, pork, and chicken will be leaving the country than actually does and more beef and pork will be entering the country than actually does.

It is shown that projecting beef, chicken, and pork exports using naïve expectations systematically underpredicts exports at nearly every horizon. This is consistent with the year-

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over-year increasing meat export volumes outlined in the introduction. If using previous years' volumes to project future volumes without recognizing the increasing trend over time, it follows that underprediction would occur. Alternatively, naïve import projections for beef and pork are neither significantly over nor underpredicted, which could be due to their more stable nature. The growth rate of meat exports far exceeds that for meat imports over the projection horizon, so relying on previous years' volumes to project future volumes is a more solid tactic for imports than exports.

Table 6 summarizes the results of the efficiency test outlined in Patton and Timmermann (2012). The joint null hypothesis H_0: $(\alpha, \beta_0) = (0, 1) \cap \gamma_h = 0$ for $h = 0, \ldots, 8$ is rejected for beef exports, beef imports, and pork imports. This suggests these projections are inefficient and are not optimal. Conversely, we fail to reject the null hypothesis for chicken exports and pork exports, signaling that these projections are efficient. Therefore, summarizing optimality tests for USDA projections, we find beef, chicken, and pork export projections, and beef and pork import projections, are all biased to some extent. Furthermore, only projections for chicken exports and pork exports are found to be efficient. Therefore, USDA meat trade projections are not optimal. We continue our analysis by examining their maximum informational horizon and by determining their relative advantage or disadvantage as compared to naïve projections.

Breitung and Knüppel (2021) test results are displayed in Tables 7 and 8. Table 7 shows Mincer-Zarnowitz $\hat{\beta}_h$ parameter estimates and their significance for testing null hypotheses $\beta_h \leq 0$ (*constant mean*) and $\beta_h \leq 0.5$ (*no information*). As stated previously, the *constant mean* hypothesis is a more relaxed test relative to the *no information* hypothesis. Inspection of the reported $\hat{\beta}_h$ estimates reveals that export projections at shorter horizons typically exhibit higher coefficient estimates. For example, at horizon $h = 0$, the $\hat{\beta}_h$ coefficient for pork exports is 0.77, but at horizon $h = 9$ that number falls to 0.37. The statistical significance of these estimates indicates that the *constant mean* null hypothesis can be rejected up to horizon $h = 4$. Horizons $h = 7$, 8, and 9 likewise indicate rejection of the constant mean null hypothesis. However, as discussed previously, h^* is determined by sequentially testing the hypotheses starting at $h = 0, 1, 2, \ldots$ until they cannot be rejected for the first time and then h^* is the penultimate horizon tested. Thus, h^* for beef exports occurs at $h = 4$. That is, USDA baseline projections for beef exports beyond horizon $h = 4$ become uninformative. For chicken and pork exports, h^* occurs at $h = 8$ and $h = 9$, respectively, if using the *constant mean* hypothesis as grounds for determination. Alternatively, the *no information* hypothesis for export projections is more stringent and implies that projections beyond $h = 2$ for pork exports are uninformative. Further, the *no information* hypothesis for beef and chicken exports suggest that projections generated in the year of the realized value ($h = 0$) are uninformative.

Beef and pork import projections' h^* occur at shorter horizons than those for exports. The constant mean hypothesis for beef imports is rejected at $h = 2$, which implies h^* occurs at $h = 1$. The no information hypothesis is rejected at $h = 0$ for beef imports, meaning projections are uninformative even when generated in the same year as the realized values. For pork imports, both the *constant mean* and *no information* hypotheses fail to be rejected at $h = 1$. Therefore, h^* for pork imports is $h = 0$. Stated differently, USDA pork import baseline projections beyond those made in the same year as the realized values are not informative.

Table 8 summarizes the maximum informative projection horizons. Generally, export projections remain informative longer than import projections when considering the *constant mean* hypothesis. However, the more conservative *no information* hypothesis suggests that only pork export and import USDA baseline projections are informative at any horizon. Even then, pork exports are informative at a horizon of $h = 2$; pork imports become uninformative after $h = 0$. These findings evince lack of usability of meat trade projections generated by USDA the greater the horizon of the projection. Notably, however, Breitung and Knüppel (2021) outline two limitations of the methodology. First, the maximum projection horizon (h^*) may be biased downward when the evaluation sample is small as is the case with this study. The second

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Table 6. Patton and Timmermann (2012) efficiency test

	Expected Value	Beef Exports	Chicken Exports	Pork Exports	Beef Imports	Pork Imports
Intercept	0	−1.21	4.91*	1.18	−7.09	33.05***
		(1.51)	(2.14)	(1.11)	(19.14)	(5.13)
Final Projection:						
$\ln P_{t,t\text{-}0}$	1	1.16***	0.45	0.87***	1.88	−3.78***
		(0.19)	(0.24)	(0.13)	(2.39)	(0.74)
Revisions:						
$\ln P_{t,t\text{-}0} - \ln P_{t,t\text{-}1}$	0	−1.11**	0.60	−0.70	−1.69	3.33***
		(0.37)	(0.55)	(0.48)	(2.39)	(0.46)
$\ln P_{t,t\text{-}1} - \ln P_{t,t\text{-}2}$	0	−1.67**	−0.11	−0.51	−1.13	2.59***
		(0.50)	(0.42)	(0.40)	(2.22)	(0.39)
$\ln P_{t,t\text{-}2} - \ln P_{t,t\text{-}3}$	0	−0.61*	−0.15	0.35	−0.50	2.50***
		(0.25)	(0.43)	(0.27)	(1.93)	(0.43)
$\ln P_{t,t\text{-}3} - \ln P_{t,t\text{-}4}$	0	−0.97**	−0.59	0.53	−1.12	1.77***
		(0.32)	(0.44)	(0.39)	(1.52)	(0.24)
$\ln P_{t,t\text{-}4} - \ln P_{t,t\text{-}5}$	0	−0.54*	0.14	−0.04	−0.94	1.03**
		(0.24)	(0.33)	(0.43)	(1.49)	(0.25)
$\ln P_{t,t\text{-}5} - \ln P_{t,t\text{-}6}$	0	−0.68**	−0.13	−0.34	−1.47	1.08***
		(0.23)	(0.43)	(0.42)	(0.99)	(0.17)
$\ln P_{t,t\text{-}6} - \ln P_{t,t\text{-}7}$	0	−0.60**	0.28	−0.23	−1.45	0.70***
		(0.20)	(0.39)	(0.42)	(0.85)	(0.14)
$\ln P_{t,t\text{-}7} - \ln P_{t,t\text{-}8}$	0	−0.49*	0.34	−0.60	−1.10	0.91**
		(0.23)	(0.39)	(0.33)	(0.51)	(0.21)
$\ln P_{t,t\text{-}8} - \ln P_{t,t\text{-}9}$	0	−0.37**	0.08	0.14	0.08	0.27**
		(0.17)	(0.24)	(0.52)	(0.65)	(0.09)
R^2		0.98	0.80	0.94	0.95	0.98
Joint test: H_0: $(\alpha, \beta_0) = (0, 1) \cap \gamma_0 = \ldots = \gamma_8 = 0$						
F-test		3.92	2.97	1.32	14.55	6.77
p-value		0.09	0.15	0.43	0.04	0.00
Degrees of freedom		4	4	4	4	4

Notes: Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level, respectively. Dependent variable, $\ln A_t$, is the natural logarithm of the actual, realized volume of exports or imports at year t. Independent variables include the final projection at horizon $h = 0$ ($\ln P_{t,t\text{-}0}$) and projection revisions leading up to the terminal event t. Projection revisions are denoted $\ln P_{t,t\text{-}h} - \ln P_{t,t\text{-}(h+1)}$, where, for example, $\ln P_{t,t\text{-}0} - \ln P_{t,t\text{-}1}$ represents the projection revision that occurred between horizons $h = 0$ and $h = 1$. Heteroskedasticity and autocorrelation consistent (HAC) standard errors are in parentheses (Newey and West, 1987).

limitation is that h^* is dependent on the methodology that produces the projection. Projections that do not exploit important information may lead to uninformative projections, while richer procedures may result in informative forecasts. That is, the information content as determined by this testing procedure is conditional on the approach that was used to generate the projections.

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Table 7. Mincer-Zarnowitz $\hat{\beta}_h$ parameter estimates

	$h = 9$	$h = 8$	$h = 7$	$h = 6$	$h = 5$	$h = 4$	$h = 3$	$h = 2$	$h = 1$	$h = 0$
Exports										
Beef	0.26***	0.14***	0.08*	−0.05	0.01	0.15***	0.27***	0.49***	0.59+++***	0.87***
Chicken	−0.04	0.19***	0.24***	0.21***	0.07*	0.12***	0.13***	0.16***	0.15***	0.36***
Pork	0.37***	0.36***	0.35***	0.36***	0.38***	0.40*	0.47**	0.61+++***	0.69+++***	0.77+++***
Imports										
Beef	0.69+***	0.86+++***	0.66++***	−0.63	−1.40	−1.07	−0.71	−0.08	0.13*	0.50***
Pork	0.08	−0.09	−0.29	−0.39	−0.45	−0.54	−0.42	−0.44	−0.37	0.62+***

Notes: Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level, respectively, for testing the null hypothesis H_0: $\beta_h \le 0$. Single, double, and triple plus signs (+,++,+++) indicate significance at the 10%, 5%, and 1% level, respectively, for testing the null hypothesis H_0: $\beta_h \le 0.5$.

Table 8. Breitung & Knüppel (2021) empirical maximum projection horizons, h^*

	H_o: *No information*	H_o: *Constant mean*
Exports		
Beef	−1	4
Chicken	−1	8
Pork	2	9
Imports		
Beef	−1	1
Pork	0	0

Table 9. MDM test

	$h = 9$	$h = 8$	$h = 7$	$h = 6$	$h = 5$	$h = 4$	$h = 3$	$h = 2$	$h = 1$	$h = 0$
Exports										
Beef	0.54	0.67	0.83	1.09	1.52	1.62	2.05*	2.82**	3.37***	0.72
Chicken	1.81*	1.46	0.72	0.54	0.37	0.31	0.00	−0.26	−1.19	−1.89*
Pork	4.85***	2.96**	2.30**	2.21**	2.38**	4.22***	3.35***	2.66**	3.19***	1.83*
Imports										
Beef	1.99*	3.06***	3.61***	2.11*	1.90*	0.56	0.33	0.02	−1.23	−2.23**
Pork	−2.44**	−0.96	−0.29	−0.25	−0.16	−0.37	−0.96	−0.81	−0.84*	−1.63

Notes: h denotes the projection horizon. Single, double, and triple asterisks (*, **, ***) indicate significance at the 10%, 5%, and 1% level, respectively.

Finally, the results of the modified Diebold-Mariano (MDM) test are presented in Table 9. Again, negative and significant MDM t-statistics suggest that naïve projection errors are significantly smaller than USDA projection errors and vice versa. Therefore, USDA appears to have a significant advantage in projecting beef and pork exports over naïve projections. More specifically, USDA more accurately projects beef exports at projection horizons $h = 1$, $h = 2$, and $h = 3$. USDA pork export projections are significantly more accurate than naïve projections at all horizons. Chicken export projections are mixed. Projections by USDA are significantly more accurate at $h = 9$, but naïve projections are significantly more accurate at $h = 0$. Similarly, USDA more accurately predicts beef imports at horizons 5 through 9, but naïve projections are significantly more accurate than USDA projections at $h = 0$. Thus, it can be concluded that the USDA projections are more accurate at longer horizons, but naïve projections perform more accurately at the shortest horizon for chicken exports and beef imports. Finally, naïve projections for pork imports are significantly more accurate than USDA projections at horizons $h = 1$ and $h = 9$.

5. Conclusion

Meat trade impacts both the profitability of U.S. meat producers and utility of U.S. meat consumers. USDA produces 10-year baseline projections for beef, pork, and chicken exports and beef and pork imports. The purpose of this paper is to assess the accuracy, optimality, and informativeness of USDA baseline projections for U.S. meat exports and imports. We compare USDA projections to naïve, no change projections. We seek to provide better understanding of the usability of these projections in decision making for stakeholders in the U.S. meat-livestock sector as well as provide suggestions to the USDA on potential methods to improve the projections going forward.

This paper finds that USDA baseline projections for beef, chicken, and pork exports and beef and pork imports are biased to some extent. Beef exports are underpredicted at short horizons, while chicken exports are underpredicted at long horizons. Pork exports are underpredicted at nearly every horizon. Conversely, beef imports are overpredicted at horizons $h = 7$ through $h = 9$, and pork imports are overpredicted at horizons $h = 5$ through $h = 8$. Only projections for chicken exports and pork exports are efficient. As such, USDA meat trade projections are not optimal. Both MAPE and RMSPE decrease as the projection horizon decreases, indicating projections made at shorter horizons become closer to the realized value. MAPE and RMSPE for USDA projections are generally below those of naïve expectations for all projections considered, and RMSPE for beef exports are considerably higher than MAPE, which could be due to the trade shock that occurred with BSE. Results of the MDM test suggest that USDA appears to have a significant advantage in projecting beef and pork exports, whereas results for chicken exports and beef and pork imports are less conclusive. In fact, naïve projections are at times favored over USDA projections for these categories, especially at short horizons.

Policymakers, industry stakeholders, and producers who utilize these projections in decision making should be aware of the limitations they possess. Foremost, meat export projections are typically underpredicted by USDA, and meat import projections are typically overpredicted. The underprediction of exports and overprediction of imports could create imbalance when predicting supply and utilization as well as domestic and international demand for meat commodities in the coming years. While USDA projections typically outperform naïve projections for meat exports, naïve projections for imports at times outperform USDA projections. Thus, stakeholders should consider using naïve import projections over USDA projections in analyses, especially at shorter projection horizons.

Results indicate that there is room for improvement in projecting volumes of U.S. meat trade. The Breitung and Knüppel test suggests that USDA meat export projections are informative at longer horizons than USDA meat import projections. As such, it is perhaps worthwhile for USDA to examine its projection generation process for exports as compared to imports to potentially improve the informational content of import projections. Additionally, there is value in considering the market for variety cuts, which include products such as tongues, hearts, livers, and so on. As these cuts are not highly demanded by the average U.S. consumer, export markets provide a critical outlet for their consumption. This, in turn, increases the value garnered from a live animal because these products are being marketed rather than being wasted. According to United States Meat Export Federation (USMEF), approximately 21% of the beef volume exported by the U.S. in 2021 was variety cuts. While this only amounts to about 10% of the beef value exported, it is still nearly $1.1 billion (USMEF, 2022b; USMEF, 2022c). The impact of pork variety cuts is likewise noteworthy. In 2021, approximately 18% of the pork volume exported by the U.S. was variety cuts, which accounted for 15% of the value of pork exported or about $1.2 billion (USMEF, 2022d; USMEF, 2022e). Clearly, variety cuts play a substantial role in the U.S. meat sector, but they are not included in USDA meat export and import projections. This suggests a potential need for USDA to consider both carcass cuts and variety cuts when projecting U.S. meat exports. Going forward, it would be of value to the U.S. meat-livestock sector to invest in further research and resources targeted at developing more encompassing meat trade projections.

Data availability. The data that support the findings of this study are available from the corresponding author, Jaime R. Luke, upon request.

Author contributions. Conceptualization, G.T.T.; methodology, G.T.T. and J.R.L.; formal analysis, J.R.L.; data curation, J.R.L.; writing-original draft, J.R.L.; writing-review and editing, J.R.L. and G.T.T.; supervision, G.T.T.; funding acquisition, G.T.T.

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Competing interests. Jaime R. Luke and Glynn T. Tonsor declare none.

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