# ESTIMATING THE INCENTIVES TO COLLUDE IN A REPEATED QUANTITY SETTING GAME

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# 1 Introduction

Since 2008, major poultry companies like Tyson Foods and Pilgrim's Pride have faced numerous civil and criminal lawsuits. These lawsuits cover a variety of allegations, including attempts to manipulate the "Georgia Dock" price, a key benchmark used in setting wholesale prices for chicken, especially broilers. This benchmark historically played a crucial role in shaping contracts and agreements between poultry companies and their clients, including large food service providers and retailers. Additionally, these companies have been implicated in a significant conspiracy to fix chicken prices, leading to a criminal antitrust lawsuit initiated by the U.S. Department of Justice, as well as many other private civil cases.

The primary objective of this study is to utilize repeated-game theory principles to analyze the likelihood of cooperative behavior among the U.S. broiler companies. We quantify the incentives of firms to collude by using publicly available data and information extracted from legal documents[1][2]. Our findings across different model scenarios offers insights into an important question: how might collusive behavior be detected? Our work will illustrate that a combination of a structural model and publicly accessible data can serve a dual purpose: (1) providing an analytical framework to identify potential incentives for firms to collude, and (2) highlighting the developments in the broiler industry, including abnormal pricing patterns, sustained production cuts, and other anomalies.

We utilize documented and observable evidence to depict the broiler market through a game-theoretic framework and estimate its essential parameters employing publicly accessible data. Our approach models alleged cartel's arrangement as a quota system, designed to optimize collective profits. This optimization takes into account factors such as the de-

[1] https://www.broilerchickenantitrustlitigation.com/Home/CourtDocuments

[2] In the realm of collusion theory, a collusive agreement is considered enforceable when the immediate benefits of defection are less than the discounted value of future profits lost by not adhering to the agreement. This concept is referred to as the 'Incentive Compatibility Constraint (ICC)'(Porter, 2020). Porter (2020) further elaborates on related concepts such as 'enforcement and participation constraints', highlighting the conditions that drive firms to conspire: they partake only if their payoffs surpass what they would obtain outside the conspiracy.

mand curve, fringe supply, and feed costs. We hypothesize that the firms engage in trigger strategies, incorporating the threat of reverting to a Cournot-Nash equilibrium if any non-compliance is detected through various trade statistics. This implies a system of perfect monitoring with a three-month delay.

Furthermore, we perform comprehensive sensitivity analyses using alternative model specifications. These variations focus on key elements such as discount factors, the duration of monitoring lags, and the composition of cartel firms. Through these analyses, we aim to provide a deeper understanding of the dynamics at play within the broiler industry as well as the factors that may influence cartel behavior. We present our findings in two steps:

(a) Profit Analysis in the Broiler Industry: Initially, we calculate three different profit scenarios under varying conditions: Cournot-Nash equilibrium profit, collusion profit, and deviation profit. In the empirical analysis, we calculate both the Nash equilibrium price and the monopoly price, and then compare these theoretical values with the actual market price. We observe that the actual market price gradually converged to the monopoly price during the period of collusion, though this alignment took some time to manifest.

(b) Collusive Incentives and Model Testing: Under a plausible assumption regarding the firms' annual discount factor, we found that the collusive incentives for the broiler cartel were consistently positive up to 2016, as revealed by many newspaper reports[3]. Subsequently, we examined different model specifications, including variations in discount factors, monitoring lags, and the composition of the cartel. Our investigation supports collusion story by providing empirical evidence related to the theoretical 'checklist' of factors influencing the sustainability of collusion (Ivaldi and Tirole, 2003). Particularly interesting are the results from experimenting with different numbers of cartel firms. Given the challenge of definitively

[3]The Wall Street Journal, in its January 18, 2016 article(Jakab, 2016), highlighted potential manipulation of the Georgia Dock Broiler price index, suggesting the possibility that broiler producers may have colluded to artificially raise, fix, or maintain broiler prices. Subsequently, the series of articles published between November 3(Storm, 2016) and 17, 2016(Whoriskey, 2016), detailed for the first time that the USDA had discontinued its reliance on the Georgia Dock price index and removed the Georgia Dock quotes from their website on August 5th, 2016.

identifying the firms involved in the cartel without concrete evidence, our approach began with all publicly listed firms, followed by analyses focusing on the top four and top seven firms, respectively.

This paper relates to a specific branch of literature within the game-theoretic approach to collusion. Traditionally, game-theoretic studies on collusion focus on scenarios where firms engage in a repeated game. In such settings, firms will maintain their collusive agreement if their individual discounted payoffs from cooperation are higher than the payoffs they would receive from cheating. Essentially, the immediate gains from cheating must be outweighed by the discounted value of the future profits lost by breaching the agreement(Porter, 2020). An agreement is self-enforcing when all firms meet their incentive compatibility constraints, ensuring that these constraints are positive.

Igami and Sugaya (2021) examines the vitamin cartels of the 1990s, presenting the study most closely related to our work. The paper treats firms as entities dealing with homogeneous products, competing in terms of quantity, and operating under constant returns to scale, albeit with varying average costs across firms. Their model posits that the cartel sets output levels to maximize joint profits while maintaining market shares at their pre-cartel levels. In this model, all cartel firms are assumed to proportionally reduce output equally. The study further delves into the incentive compatibility condition (ICC) for each firm, considering a specific discount factor, and concludes that a cartel remains stable as long as the ICC is satisfied for every member firm. They observe that the vitamin C cartel disintegrated following an expansion in fringe supply, which led to the non-satisfaction of the ICC conditions for some firms.

Many other studies within this field of literature focus on delineating the incentive compatibility constraint through the lens of a firm's critical discount factor. This factor is defined by a point of indifference between the choice to defect from a cartel agreement and the subsequent losses incurred due to any ensuing punishment after cheating has been detected. A collusive agreement is deemed stable or self-enforcing when each participant's discount factor

exceeds their respective critical discount factor. Ivaldi and Lagos (2017) analyze a context framed by a random coefficient logit demand model and define the perfect equilibrium of a supergame where firms engage in an infinitely repeated game, employing grim trigger strategies. This analysis delves into the incentive constraints linked to the maximization of joint profits and effectively derives the critical discount factor.

The incentive compatibility conditions and the firms' critical discount factors depend on some determinants that will impact cartel stability and duration. Literature following such a dynamic approach basically recognizes that market concentration facilitates collusion (Levenstein and Suslow, 2006). A negative relationship between the number of firms in a market and cartel success is also supported by empirical evidence (Frass and Greer, 1977; Davies et al., 2011) and by experimental evidence.

This paper contributes to the collusion literature by studying the conditions for collusion stability in a Cournot oligopoly with a competitive fringe when collusion is enforced via a trigger strategy, like (Friedman, 1971). The novelty of our study lies in its empirical approach, focusing on the sizes of cartels and the asymmetries among cartel firms. While Lei (2011) offers an analytical framework to ascertain the size of stable cartels in a symmetric oligopoly model with a Cournot fringe, building upon the conjectures of Konishi and Lin (1999) and validating them through numerical simulations, these studies typically assume homogeneity among firms, which may not align with real-world scenarios. Our research departs from this traditional assumption, introducing a model that accounts for constant disparities in costs among firms with varying market shares, thus offering a more nuanced and realistic analysis of cartel dynamics.

Our paper also sheds light on the discrepancies between standard theoretical predictions and real-world evidence regarding cartels. Conventional wisdom suggests that cartels are most likely to form in markets with a few symmetric firms, typically no more than three or four. However, established literature on prosecuted cartels in the US reveals some intriguing findings (Levenstein and Suslow, 2006). Notably, various studies across the 20th century

show that the median number of cartel members often ranges between six and ten, with larger cartels tending to have greater longevity (Hay and Kelley, 1974; Frass and Greer, 1977). More recent research on cartels prosecuted by the European Commission between 1990 and 2006 found a median of five firms per cartel (Davies and Olczak, 2008). Our sensitivity analysis, particularly with regard to the number of cartel firms, corroborates these real-world observations, demonstrating increased sustainability of the cartel with the involvement of the top seven firms, compared with only 3 or 4 firms.

The remainder of this paper is structured as follows: Section 2 talks about the industry structure, specifies the collusion period, and details the datasets utilized in the study. Section 3 delves into the theoretical and empirical models employed, accompanied by a presentation of our estimations. In Section 5, we explore the profits of the stage-game under various scenarios. Section 6 introduces our repeated-games model, applying this dynamic framework to calculate the incentives for firms to engage in collusion. Section 7 presents the outcomes derived from different model assumptions and discusses the implications arising from our choice of models. Section 8 concludes the paper.

# 2 Preliminaries

## 2.1 Alleged Conspirators

The broiler antitrust sequence of litigations involve allegations against several major broiler chicken producers in the United States. These companies are accused of conspiring to fix prices and manipulate the supply of broiler chickens to inflate prices. The firms implicated in these litigations include Tyson Foods, Pilgrim's Pride, Sanderson Farms, Perdue, Koch Foods, among others. Additionally, a class action litigation represents direct purchasers of broiler chickens from 17 broiler producers, suggesting a wide net of implicated companies. This includes not only the ones mentioned above but also others such as Fieldale Farms,

George's, O.K. Foods, Mar-Jac Poultry, Claxton Poultry, and Harrison Poultry.

The allegations suggest that these companies engaged in practices such as sharing confidential production information, coordinating supply restrictions, and manipulating the Georgia Dock price index—a widely used benchmark for broiler chicken prices. These actions are claimed to violate federal antitrust laws, specifically the Sherman Act, by restraining competition and manipulating market prices. Several lawsuits have been filed on behalf of different plaintiff groups, including direct purchasers of broiler chickens, end-user consumers, and commercial purchasers. These lawsuits have been consolidated into multidistrict litigation (MDL) in the United States District Court for the Northern District of Illinois.

To gain a better understanding of which firms are most frequently listed as defendants in collusive behavior lawsuits, it is essential to examine court dockets. Court cases generate a variety of documents beyond final opinions, including briefs, trial transcripts, and jury instructions. These documents, found in court dockets, reveal arguments that influenced the court and provide context for factual issues not detailed in published opinions. They also showcase how attorneys formatted and presented documents. By obtaining the number of dockets with the keyword "Collusion" from Docket Alarm [4], we can identify the most mentioned firms. The Table 1 displays the total number of dockets for each firm that include any of the following terms: "collusion," "price-fix," and "price-fixing. The Table 1 reveals several insights. Examining the numbers across different time periods, it is evident that most case dockets emerged following the discovery of collusive behavior in the broiler industry. This is logical for two reasons: firstly, legal dockets naturally appear as lawsuits progress; secondly, the abnormal signs in the broiler industry, such as historically high broiler prices and reduced supply, have increasingly drawn attention from individuals, firms, and organizations.

Among broiler firms, Tyson consistently shows a high number of dockets across all peri-

[4]Docket Alarm is a legal research platform that provides access to court dockets, filings, and case documents from federal, state, and local courts. It is used by legal professionals to track case progress, review filings, and gather insights into legal strategies and outcomes. https://www.docketalarm.com/dockets/

ods, indicating sustained legal scrutiny. Following Tyson, Wayne Farms and Foster Farms have a similar number of legal dockets, and they are followed by Harrison, Perdue, Sanderson, Simmons, Koch, and Pilgrim's Pride. There is a noticeable gap in the number of dockets between these top nine firms and the remaining firms, highlighting the concentration of legal activity among the leading firms in the broiler industry.

Table 1: The total number of dockets with keyword "Collusion/ Price-fix /Price-fixing"

| Firm | Total dockets (2004-2023) | Total dockets (2008-2023) | Total dockets (2017-2023) |
|---|---|---|---|
| Tyson | 843 | 842 | 813 |
| Wayne | 737 | 736 | 684 |
| Foster | 723 | 721 | 665 |
| Harrison | 605 | 602 | 555 |
| Perdue | 520 | 520 | 506 |
| Sanderson | 493 | 493 | 480 |
| Simmons | 456 | 455 | 436 |
| Koch | 427 | 424 | 400 |
| Pilgrim | 403 | 403 | 392 |
| Fieldale | 346 | 346 | 337 |
| Peco | 322 | 322 | 312 |
| Claxton | 320 | 320 | 316 |
| Raeford | 320 | 320 | 312 |
| Mountaire | 294 | 294 | 287 |
| Mar-Jac | 290 | 290 | 287 |
| OK Foods | 132 | 132 | 131 |

Table 2: Defendant shares
Firm-level live-weight/Total young chicken slaughtered live-weight
2001-2020

| *(percentages)* | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tyson | 23.80 | 23.61 | 23.77 | 23.45 | 22.73 | 22.19 | 20.66 | 20.05 | 21.64 | 21.69 | 21.51 | 20.68 | 20.81 | 20.32 | 19.79 | 19.47 | 19.19 | 21.64 | 20.49 | 20.24 |
| Pilgrim's Pride | 8.95 | 8.74 | 15.75 | 15.55 | 15.86 | 25.04 | 23.74 | 21.35 | 18.94 | 17.10 | 17.60 | 17.44 | 18.41 | 16.41 | 16.12 | 15.89 | 16.29 | 15.48 | 15.63 | 15.81 |
| Perdue | 7.34 | 7.29 | 7.23 | 7.42 | 6.48 | 7.73 | 7.57 | 7.37 | 7.59 | 7.26 | 7.15 | 7.18 | 7.21 | 7.15 | 7.55 | 7.51 | 7.40 | 7.41 | 7.03 | 6.73 |
| Wayne Farms | 3.99 | 4.10 | 4.01 | 3.82 | 3.90 | 4.30 | 4.20 | 4.13 | 4.12 | 4.20 | 4.49 | 4.41 | 5.01 | 5.19 | 5.20 | 5.02 | 4.91 | 4.86 | 4.90 | 4.80 |
| Sanderson | 3.47 | 3.65 | 3.89 | 3.99 | 3.95 | 4.40 | 4.85 | 5.70 | 5.89 | 6.01 | 6.53 | 6.84 | 6.83 | 6.74 | 7.11 | 7.62 | 8.29 | 8.62 | 8.71 | 9.01 |
| Foster Farms | 3.79 | 3.19 | 3.13 | 3.21 | 3.31 | 3.16 | 3.05 | 3.05 | 3.30 | 3.51 | 3.62 | 3.74 | 3.68 | 3.47 | 3.44 | 3.22 | 3.15 | 2.79 | 3.09 | 3.01 |
| Mountaire | 2.96 | 3.03 | 3.20 | 3.33 | 3.44 | 3.66 | 3.97 | 3.98 | 4.13 | 4.17 | 4.41 | 4.73 | 4.82 | 5.04 | 5.09 | 5.07 | 5.12 | 5.04 | 5.68 | 6.03 |
| Fieldale Farms | 1.88 | 1.80 | 1.80 | 1.78 | 1.76 | 1.84 | 1.78 | 1.90 | 2.04 | 1.97 | 1.96 | 1.87 | 1.77 | 1.83 | 1.87 | 1.92 | 1.88 | 1.84 | 1.83 | 1.80 |
| Koch | 0.95 | 2.00 | 2.08 | 2.00 | 1.94 | 2.71 | 2.67 | 2.63 | 4.86 | 5.01 | 4.98 | 6.45 | 6.32 | 6.22 | 5.99 | 6.12 | 5.98 | 5.85 | 6.45 | 6.36 |
| Claxton Poultry | 0.86 | 0.85 | 0.88 | 0.86 | 0.84 | 0.83 | 0.82 | 0.80 | 0.87 | 0.84 | 0.92 | 0.97 | 1.00 | 1.01 | 0.99 | 1.01 | 1.02 | 1.03 | 0.97 | 0.96 |
| OK Foods | 2.30 | 1.93 | 2.21 | 2.32 | 2.25 | 2.26 | 2.23 | 2.00 | 2.20 | 2.12 | 1.71 | 1.95 | 1.91 | 1.88 | 1.81 | 1.63 | 1.63 | 1.60 | 1.55 | 1.53 |
| Peco | 1.84 | 1.85 | 1.91 | 2.34 | 2.47 | 2.22 | 2.07 | 2.19 | 2.59 | 2.63 | 3.04 | 3.21 | 3.27 | 3.20 | 3.30 | 3.58 | 4.16 | 4.21 | 4.09 | 3.98 |
| Mar-Jac | 0.90 | 0.87 | 0.93 | 0.90 | 0.87 | 0.86 | 0.93 | 0.92 | 0.96 | 0.93 | 0.92 | 0.92 | 0.90 | 1.91 | 1.87 | 1.86 | 1.80 | 1.76 | 1.71 | 1.68 |
| Harrison Poultry | 0.50 | 0.50 | 0.60 | 0.60 | 0.60 | 0.60 | 0.63 | 0.63 | 0.62 | 0.61 | 0.66 | 0.68 | 0.71 | 0.70 | 0.67 | 0.58 | 0.55 | 0.54 | 0.53 | 0.54 |
| House of Raeford | 1.84 | 1.83 | 1.99 | 2.11 | 2.19 | 2.62 | 3.08 | 2.88 | 2.84 | 3.01 | 2.74 | 2.90 | 2.98 | 3.09 | 3.12 | 3.03 | 3.02 | 2.90 | 2.85 | 3.07 |
| Simmons | 1.51 | 1.51 | 1.38 | 1.45 | 1.50 | 1.47 | 1.60 | 1.92 | 2.01 | 2.21 | 1.78 | 1.77 | 1.76 | 1.73 | 1.80 | 1.82 | 1.82 | 1.78 | 1.78 | 2.43 |
| George's | 2.18 | 2.11 | 2.11 | 2.04 | 2.10 | 2.09 | 2.10 | 2.02 | 2.04 | 2.14 | 2.21 | 2.51 | 2.44 | 2.47 | 2.37 | 2.44 | 2.47 | 3.13 | 3.11 | 3.10 |
| Case Farms | 1.09 | 1.13 | 1.10 | 1.16 | 1.21 | 1.24 | 1.30 | 1.40 | 1.58 | 1.61 | 1.63 | 1.93 | 2.01 | 2.10 | 2.08 | 2.12 | 2.11 | 2.07 | 2.09 | 2.09 |
| Amick Farms | 0.60 | 0.70 | 0.70 | 0.70 | 0.82 | 0.86 | 0.98 | 1.00 | 1.16 | 1.49 | 1.86 | 1.90 | 1.88 | 1.98 | 2.23 | 2.37 | 2.27 | 2.27 | 2.38 | 2.43 |
| Total | 70.75 | 70.69 | 78.67 | 79.03 | 78.22 | 90.08 | 88.23 | 85.92 | 89.38 | 88.51 | 89.72 | 92.08 | 93.72 | 92.44 | 92.4 | 92.28 | 93.06 | 94.82 | 94.87 | 95.6 |

Table 2 presents the market shares of all defendant firms from 2001 to 2020. As discussed above, the nine companies, due to their frequent citations in broiler litigation cases, will be categorized as the collusive group. This group is presumed to collaborate with one another to optimize their output through collusion. Conversely, the remainder of the broiler industry, encompassing 10 other firms listed in Table 2 as well as all smaller broiler firms not mentioned above, will be treated as a competitive fringe.

## 2.2 Collusion Period

Historically, the most commonly referenced broiler price data were derived from three sources: Urner Barry (a commodity price reporting service), the Georgia Department of Agriculture (also known as 'Georgia Dock'), and the USDA. Historically all three price series moved very closely together. Figure 1 illustrates the trends in Georgia Dock and USDA Composite RTC prices from 2000 to 2020. Notably, starting in 2008, a significant divergence occurred between the Georgia Dock price and the USDA composite price index. While the USDA price began to decline in 2008, the Georgia Dock price persistently remained at a considerably higher level. This divergence raised immediate suspicions and has been construed by plaintiffs in various litigation cases against broiler companies as indicative of potential price manipulation and collusion.

"On May 21, 2008, The Wall Street Journal published an article highlighting emerging shifts in the broiler industry. The article noted three factors contributing to a more optimistic outlook among analysts: a reduction in production by companies, a decrease in weekly egg-set numbers (egg sets refer to fertile eggs placed in incubators), and a positive response in prices due to diminishing supply lines. Furthermore, the article remarked on the atypical nature of a decline in egg sets during that time of year. Such a reduction in May is unusual because eggs set into incubators typically yield broilers ready for the market approximately 10 weeks later, which, in this instance, would align with the first week of August. This period falls squarely within the peak of the high-demand summer grilling season. Based on

these observations, we identify the onset of 2008 as the beginning of the collusion period in the broiler industry.

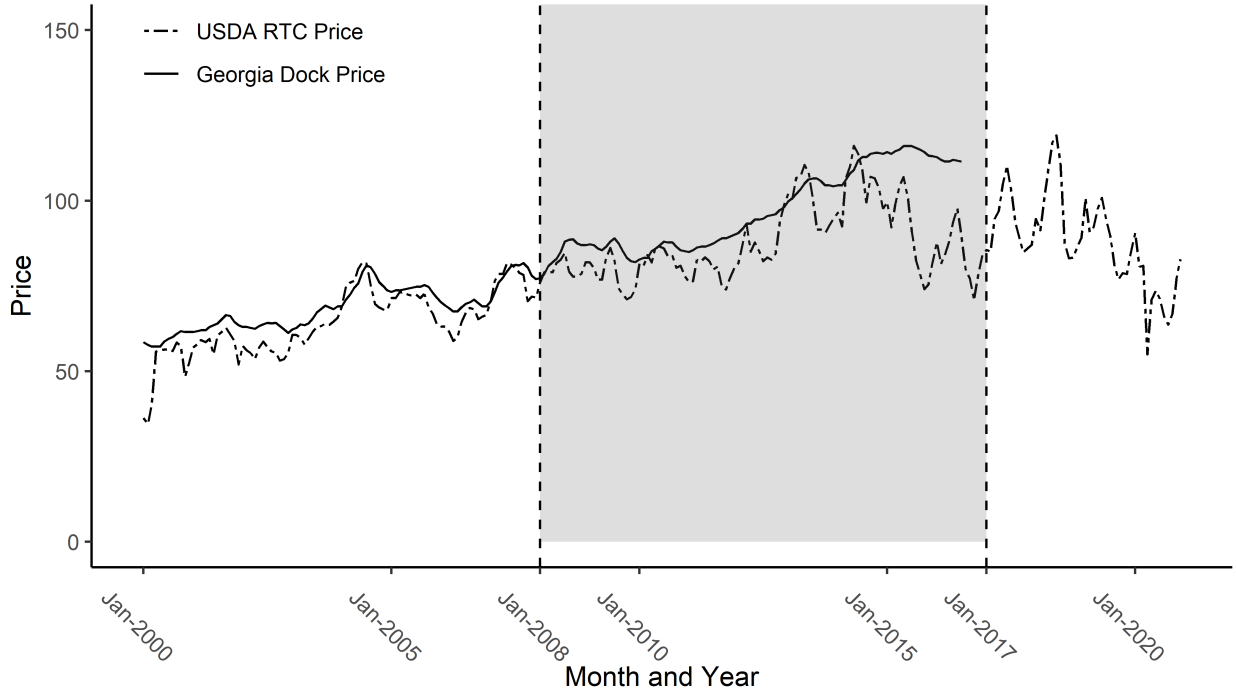



Figure 1: Broiler Prices of Georgia Dock and USDA RTC prices

Several years later, a significant development occurred, as highlighted by The Wall Street Journal in an article dated January 18, 2016. This article brought to light the potential manipulation of the Georgia Dock Broiler price index, suggesting the possibility of broiler producers colluding to artificially elevate, fix, or sustain broiler prices. A subsequent series of articles, published between November 3 and 17, 2016, revealed for the first time that the USDA had ceased using the Georgia Dock price index. This change was marked by the removal of the Georgia Dock quotes from their website on August 5, 2016. Thereafter, beginning in October 2016, the USDA started providing more detailed information in its own price indices, a move that effectively discredited the Georgia Dock price. Based on these developments, we identify 2016 as marking the conclusion of the collusion period in the broiler industry.

Drawing from the aforementioned findings, we designate the period from 2008 to 2016

as the potential collusion period for the purposes of our research. Referring back to Figure 1, it is evident that broiler prices were markedly higher during this period. This deviates from the expected pricing dynamics in a competitive market. For example, throughout much of the Great Recession, broiler prices consistently increased, despite stagnant or declining input costs. Similarly, during 2015-2016, broiler prices remained elevated, not reflecting the significant decrease in corn and soybean prices, which represent 50-70% of the cost inputs for broilers.

## 2.3 Publicly Available Data

We employ two primary categories of data: Industry-level data encompassing poultry prices and output quantities, and Firm-level output quantities. In addition, we use data on corn and soybean meal prices to estimate the cost of feed, the primary cost component in live bird production. These datasets are utilized to estimate demand, marginal cost and first-order conditions. The results are subsequently applied to various scenarios to estimate profits, and then to derive the incentive to collude. Table 3 shows the summary statistics by subsamples: pre-collusion period ($I_t = 0$), collusion period ($I_t = 1$), post-collusion period ($I_t = 0$), and the full period. The full sample period is from January 2001 to December 2020 and the stipulated collusion period is January 2008-December 2016.

Table 3: Price and Quantity Data Summary Statistics

| Variable | Mean (and Standard Deviation) | | | |
|---|---|---|---|---|
| | Pre-Collusion Period ($I_t = 0$) | Collusion Period ($I_t = 1$) | Post-Collusion Period ($I_t = 0$) | Full Period |
| RTC Price (cent/pound) | 66.05 | 87.35 | 88.30 | 80.08 |
| | (8.11) | (10.93) | (13.60) | (14.81) |
| Aggregate Output (1,000 pound) | 3345.36 | 3694.07 | 4142.08 | 3,662 |
| | (241.50) | (217.78) | (244.16) | (367.70) |
| Output of Tyson | 764.15 | 762.27 | 844.77 | 779 |
| | (47.64) | (38.58) | (63.79) | (57.68) |
| Output of Pilgrim | 550.71 | 652.40 | 654.42 | 617 |
| | (223.84) | (58.21) | (38.41) | (146.97) |
| Output of Perdue | 244.14 | 270.82 | 295.62 | 617 |
| | (22.57) | (17.96) | (17.55) | (146.97) |
| Output of Wayne | 135.44 | 171.91 | 201.59 | 617 |
| | (12.30) | (22.89) | (11.60) | (146.97) |
| Output of Sanderson | 216.62 | 243.87 | 358.82 | 229 |
| | (110.43) | (31.93) | (26.74) | (85.59) |
| Output of Mountaire | 113.20 | 170.53 | 226.80 | 617 |
| | (17.31) | (22.17) | (24.99) | (146.97) |
| Output of Koch | 69.26 | 200.02 | 255.34 | 617 |
| | (20.92) | (46.66) | (20.79) | (146.97) |
| Output of Fringe | 1333.09 | 1222.24 | 1304.73 | 2,036 |
| | (186.21) | (82.85) | (74.26) | (205.71) |
| Pork Price (cent/pound) | 117.28 | 147.13 | 147.24 | 136.70 |
| | (11.45) | (22.89) | (18.56) | (23.49) |
| Corn Price (cent/pound) | 4.18 | 8.43 | 6.29 | 6.52 |
| | (0.91) | (2.29) | (0.43) | (2.50) |
| Soybean Meal Price (cent/pound) | 10.08 | 19.12 | 14.98 | 15.13 |
| | (2.35) | (3.36) | (1.02) | (4.83) |
| Number of months | 84 | 108 | 48 | 240 |

Prices: Our analysis employs wholesale prices for ready-to-cook broilers, which refers to broiler meat prepared for the marketing channel. The national ready-to-cook (RTC) prices encompass whole-body birds with or without giblets, spanning all grades, brands, and packaging variations. These prices are collected across three regions: eastern, central, and western regions. We gathered weekly national ready-to-cook (RTC) broiler wholesale prices from the Weekly Composite Weighted Average Prices for RTC Broiler/Fryers Reports and Weekly National Whole Broiler/Fryer Reports. To facilitate our analysis, we transformed this weekly data into monthly data by computing the monthly average prices.

National and firm-level output: We acquired monthly national ready-to-cook (RTC) broiler quantity data spanning from 2001 to 2021, sourced from the USDA Poultry Slaughter Annual Summary. This dataset includes state and U.S. aggregates of the number of chickens, turkeys, ducks, and other poultry slaughtered under federal inspection, along with their live weight. Our specific focus within this dataset pertains to the chilled and frozen pounds of certified young chickens slaughtered under Federal inspection. The individual firm-level quantity data is sourced from the WATT PoultryUSA annual surveys of the leading U.S. broiler companies. This dataset encompasses yearly ready-to-cook (RTC) quantities, total live weight, the number of heads, and the average live weight. To derive meaningful insights, we combine this data with the USDA national aggregates and compute the annual market shares of each firm, based on live weights[5]. We make the assumption that firm shares remain constant throughout each year and then proceed to calculate the monthly firm-level RTC quantities by multiplying the annual national total RTC quantities by the annual market share of each firm.

Demand and Supply Shifters: We use the pork price ($P_{\text{pork}}$) as a demand shifter. The pork prices are sourced from the USDA ERS (Economic Research Service) Meat Price Spreads,

[5]The WATT Poultry USA annual surveys provide quantity data for both total live weight and RTC weight. Ideally, for consistency, we should have employed RTC weight to calculate each firm's market share. However, due to unexplained discrepancies, the summation of market shares calculated using RTC weight exceeds 1, which is logically impossible. Consequently, we have opted to utilize total live weight to determine the market share for each firm.

which offers monthly average prices at various stages – farm, wholesale, and retail – for selected cuts of beef, pork, and chicken. On the supply side, we utilize monthly prices of corn and soybean meal obtained from the USDA Quick Stats database, reflecting key cost inputs in the production process.

# 3 Industry Structure, Demand, and Marginal Costs

## 3.1 Industry Model

A noteworthy aspect of the poultry industry is that while the largest poultry corporations hold a significantly greater portion of the market compared to others, the cumulative market share of the remaining companies also constitutes a substantial portion. The fact that prior to the collusion period only 19 broiler companies controlled about 90% of the entire market and top-3 companies controlled about 55% of the market, it would be difficult to argue that the industry is perfectly competitive. However, from a game-theoretic point of view, claiming that all 19 firms are strategic competitors also does not make too much sense, hence a natural choice becomes a Cournot with competitive fringe model. Therefore, on the supply side we assume that $N^c = 9$ firms belong to the cartel and collectively produce $Q_{car,t}$, whereas $N^f$ firms in the competitive fringe supplies $Q_{fri,t}$.

We posit that firms within the cartel adopt varying strategies across different periods. During non-collusion periods, each strategic firm behaves as a Cournot oligopolist where the individual quantities are determined in the Nash equilibrium. Conversely, in the collusion period, these firms engage in collective action, effectively operating as a unified monopoly. This strategic collaboration involves maximizing the cartel's overall profit. In a two-stage game, the cartel makes its output decisions first, factoring in the response of the competitive fringe. Following the cartel's choice, price-taking firms then determine their output levels

by setting price equals marginal cost. The total output $Q_t = Q_{car,t} + Q_{fri,t}$, where $Q_{fri,t} = \sum_{j=1}^{N^f} q_j$ is the output supplied by all price-taking firms within the competitive fringe, and $Q_{car,t} = \sum_{i=1}^{N^c} q_i$ is the output supplied by all firms in the cartel. The model can be solved using backward induction as follows:

In the second stage, each firm $j$ in the competitive fringe tries to maximize its own profit by choosing production quantity, given the production of the cartel. Since all competitive firms are price-takers, the condition could be written as

$$P(Q_{car} + q_j + \sum_{l \neq j} q_l) = MC(q_j) \tag{1}$$

where $j \in \{1, 2, ..., N^f\}$. By solving the first-order condition, we could obtain the optimal choice $q_j^*(Q_{car,t})$, and the optimal output of the competitive fringe $Q_{fri}^* = \sum_{j=1}^{N^f} q_j^*(Q_{car})$.

In the first stage, during the competitive periods, we assume a static Nash equilibrium of the quantity game played by collusive firms. Each firm $i$ has the expectation of competitive fringe's reaction and chooses quantity $q_i$ to maximize its own profit:

$$\pi_i = \max_{q_i} P\Big(Q_{fri}^* + q_i + \sum_{m \neq i} q_m\Big) q_i - C_i(q_i) \tag{2}$$

where $i \in \{1, 2, ..., N^c\}$. Then take the first order condition, we will get:

$$\begin{aligned}
\frac{\partial \pi_i}{\partial q_i} &= P + \frac{\partial P}{\partial q_i} q_i - MC_i(q_i) \\
&= P + \frac{\partial P}{\partial Q_{car}} \frac{\partial Q_{car}}{\partial q_i} q_i - MC_i(q_i) \\
&= P + \frac{\partial P}{\partial Q_{car}} \frac{\partial (q_i + \sum_{m \neq i} q_m)}{\partial q_i} q_i - MC_i(q_i) \\
&= P + \frac{\partial P}{\partial Q_{car}} q_i - MC_i(q_i) = 0
\end{aligned} \tag{3}$$

where $\frac{\partial P}{\partial q_i}$ is the marginal effect of firm $i$'s output on market price, and $\frac{\partial P}{\partial Q_{car}}$ is the slope of

the residual demand curve (net of $Q_{fri,t}$). Equation (3) can be re-written as:

$$\begin{aligned} MC_i(q_i) &= P + \frac{\partial P}{\partial Q_{car}} q_i \\ &= P + \frac{\partial P}{\partial Q_{car}} \frac{Q_{car}}{P} \frac{P}{Q_{car}} q_i \\ &= P + \frac{\partial P/P}{\partial Q_{car}/Q_{car}} \frac{q_i}{Q_{car}} P \\ &= P + \frac{1}{\varepsilon^{car}} s_i^{car} P \end{aligned} \tag{4}$$

where $\varepsilon^{car} = \frac{\partial Q_{car}}{\partial P} \frac{P}{Q_{car}}$ is the price elasticity of cartel demand for output and $s_i^{car} = \frac{q_i}{Q_{car}} = \frac{q_i/Q}{Q_{car}/Q}$ refers to the within-cartel market share of collusive firm $i$'s production, expressed as a proportion of the total cartel production. This is also equivalent to the ratio of firm $i$'s market share compared to the overall market share held by the cartel:

$$\frac{P - MC_i(q_i)}{P} = -\frac{s_i^{car}}{\varepsilon^{car}} \tag{5}$$

Equation (5), also known as the Lerner index (Lerner, 1934), suggests that collusive firms with larger market shares will have lower marginal costs. It further indicates that less elastic market demand lead to larger margins and more pronounced disparities in marginal costs across firms.

## 3.2 Estimating Demand, Marginal Costs and First-Order Conditions

We specify a linear poultry demand model as:

$$Q_t = a_0 + a_1 P_t + a_2 P_{pork,t} + a_3 t + a_4 t^2 + D_m + e_t \tag{6}$$

where $Q_t = \sum_{i=1}^{N} q_i$ is per period total industry output, $P_t$ is RTC broiler price, and $p_{pork,t}$ is the prices of pork, the main substitute for poultry. Quantity is measured by the RTC pounds, prices are monthly weighted average prices expressed on the RTC weight basis, and $t$ and $t^2$ specify the linear and quadratic time trend. $D_m$ indicates 11 monthly dummies. December is left out to avoid multi-collinearity. $a_1 \frac{P}{Q}$ is the estimator of the own price elasticity of demand for broiler, previously labeled as $\varepsilon$.

There are several estimation issues that should be addressed. First, following Schroeter (1988), we assume that the error $e_t$ with the property $E(e_t) = 0$, follows an AR(1) process. Second, the error term may also be heteroscedastic. Serial correlation and heteroscedasticity in the error term do not affect the consistency of the estimated coefficients, but failing to control for them would adversely affect inference. To obtain the correct standard errors of estimated coefficients in all regressions, we used the kernel-based heteroscedasticity and autocorrelation consistent standard error estimator proposed by Newey and West (1987). The kernel that has been selected is Bartlett kernel, and the bandwidth parameter is set to 2, in a way that is consistent with the AR (1) assumption for the error term.

Finally, the right-hand side prices $P_t$ might be endogenous since the equilibrium price is simultaneously determined with equilibrium quantities. Accordingly, we adopt single-equation two-step optimal GMM estimation. We need to define instrumental variables to identify the model and perform the estimation. Supply shifters are normally good candidates for instruments for the demand function. The minimal duration of the entire broiler cycle from the placement of breeder pullets to the harvesting of mature broilers is about 7 months. Therefore, feed prices at the beginning of the cycle are likely to be more relevant to firms' decisions on how many broilers to produce than contemporaneous feed prices. With these insights, we use the instrument $Feed_{t-7}$.

To estimate the feed cost for each pound of RTC broiler, we need to know the feed conversion ratio for producing broilers, which is defined as the weight of feed needed to yield one pound live weight of the chicken. Feed price is calculated as the weighted average price

of corn (70%) and soybean meal (30%), the two main components of chicken feed. Therefore, the feed cost per pound of RTC broilers is calculated as: $c_{feed,t} = \frac{(70\% * Corn + 30\% * SoybeanMeal)\kappa}{\lambda}$ where $\kappa$ is the feed conversion rate and $\lambda$ is the processing yield (the ratio of live weight to processed weight). We use $\kappa = 1.74$ (MacDonald, 2014) and $\lambda = 0.71$ (Aberle, 2001). The estimation results are presented in Table 4.

The estimation results show that the RTC prices, a primary focus of our analysis and pivotal for subsequent examinations, stands at -24.4802 and is statistically significant, which gives the price elasticity of demand of $\varepsilon = -0.4224$ (evaluated at the annual average price and quantity data from 2020). Our finding is consistent with most of the literature in this area, see for example Chi and Lovett (2020).

The reliability of our results hinges on the quality of our instrumental variables (IVs). To assess this, we conducted both underidentification and weak-identification tests for the IVs. The underidentification test involves a Lagrange multiplier (LM) test to determine if the instruments are correlated with the endogenous variables. In the null hypothesis, the instruments are assumed to be uncorrelated with the endogenous regressors. The corresponding statistic follows a chi-squared distribution with $(L1 - K1 + 1)$ degrees of freedom, where $L1$ represents the number of IVs and $K1$ is the count of endogenous variables. In our case, we employed the Kleibergen-Paap rk LM statistic for the underidentification test, especially when the assumption of ïndependent and identically distributed(i.i.d) errors is relaxed. Notably, the Kleibergen-Paap rk LM statistic in our model significantly exceeds the critical value at the 5% significance level, with a p-value of 0.0142. Therefore, we confidently reject the null hypothesis of underidentification at the 5% level. When instruments are correlated with endogenous variables but exhibit weak correlation, the estimators may perform inadequately. To test for weak identification, especially in cases where the error term is not i.i.d., we employed the Kleibergen-Paap Wald rk F statistic. It is worth noting that the instrument we selected also passes the weak-identification test.

Table 4: Estimation Results for Demand Function

| Variable | Coef. | Robust St. Dev | P-value |
|---|---|---|---|
| P | -24.4802 | 8.7252 | 0.05 |
| Pork | 3.1207 | 2.0959 | 0.136 |
| $t$ | 12.6246 | 3.3057 | 0.000 |
| $t^2$ | -0.0220 | 0.0104 | 0.035 |
| $D_1(January)$ | 267.639 | 71.4793 | 0.000 |
| $D_2(February)$ | -97.7064 | 54.7860 | 0.075 |
| $D_3(March)$ | 286.9472 | 68.1502 | 0.000 |
| $D_4(April)$ | 181.6596 | 83.5500 | 0.030 |
| $D_5(May)$ | 404.1397 | 99.1703 | 0.000 |
| $D_6(June)$ | 350.0512 | 86.2357 | 0.000 |
| $D_7(July)$ | 274.2779 | 75.8038 | 0.000 |
| $D_8(August)$ | 272.4523 | 63.9714 | 0.000 |
| $D_9(September)$ | 69.9161 | 59.9300 | 0.243 |
| $D_{10}(October)$ | 295.9942 | 78.393 | 0.000 |
| $D_{11}(November)$ | -53.0907 | 53.7685 | 0.323 |
| Constant | 3910.813 | 276.2392 | 0.000 |
| Kleibergen-Paap rk LM statistic: 6.010 | | | |
| Chi-sq(1) P-val= 0.0142 | | | |
| Kleibergen-Paap rk Wald F statistic: 8.486 | | | |

*Note: the coefficients are estimated using the entire period 2001-2020*

Next, we need to estimate the supply function for the competitive fringe. We propose

the following specification:

$$Q_{fri,t} = b_0 + b1P_t + b2Feed_{t-7} + e_{st} \tag{7}$$

where $Feed_{t-7}$ represents the feed price seven months ago because the complete broiler cycle, spanning from the placement of breeder pullets to the harvesting of mature broilers, typically extends over a duration of approximately 7 months. Similarly to estimating the demand function, here we also assume that the error term $e_t$ with the property $E(e_t) = 0$, follows an AR(1) process, and could also be heteroscedastic. To solve the problem of endogeneity, we adopt a demand shifter, pork price, as an instrument. An estimator of the orice elasticity of supply from the competitive fringe is given by $b_1 \frac{P_t}{Q_{fri,t}}$.

Table 5: Estimation Results for Supply Function of the Competitive Fringe

| Variable | Coef. | Robust St. Dev | P-value |
|---|---|---|---|
| P | 5.3004 | 1.5859 | 0.001 |
| Feed_7 | –14.1935 | 2.2319 | 0.000 |
| Constant | 1117.443 | 98.2499 | 0.000 |
| Kleibergen-Paap rk LM statistic: 17.367 | | | |
| Chi-sq(1) P-val= 0.0000 | | | |
| Kleibergen-Paap rk Wald F statistic: 37.563 | | | |

*Note: the coefficients are estimated using the entire period 2001-2020*

As seen from Table 5, the coefficient associated with the RTC price of 5.3004, is statistically significant, and is used to calculate the price elasticity of supply for the competitive fringe of 0.3714. Additionally, the results suggest that an increase in feed prices leads to a reduction in supply by the competitive fringe. The robustness of our instrumental variable is also rigorously tested. The Kleibergen-Paap rk LM statistic in our model significantly surpasses the critical value at the 1% significance level, with a p-value of 0.000. This effectively

rejects the null hypothesis that our instrument is uncorrelated with the endogenous regressors. To address concerns of weak identification, particularly in scenarios where the error term is not identically and independently distributed (i.i.d.), we employed the Kleibergen-Paap Wald rk F statistic. It is noteworthy that the selected instrument satisfactorily passes the weak-identification test as well.

Upon estimating the market demand and supply functions for the competitive fringe, we can determine the residual demand facing the cartel as follows:

$$Q_{car,t} = Q_t - Q_{fri,t} = (a_1 - b_1)P_t + (a_0 + a_3 t + a_4 t^2 - b_0 - b_2 Feed_{t-7}) \tag{8}$$

Based on (8) $\frac{\partial Q_{car}}{\partial P_t} = a_1 - b_1$ represents the slope of the residual demand curve, and the elasticity of the residual demand facing the cartel is $\varepsilon^{car} = \frac{\partial Q_{car}}{\partial P_t}\frac{P_t}{Q_{car}} = (a_1 - b_1)\frac{P_t}{Q_{car}}$.

Finally, we need to make some assumptions regarding the cost structure for each firm. Given the cartel firms' relatively stable market shares, we assume constant gaps exist between their true (unobserved) marginal costs $c_{i,t}$ and unit feed cost (observed),

$$c_{i,t} = c_{feed,t} + \gamma_i + \theta_{i,t} \tag{9}$$

where $\gamma_i$ is the mean difference between $MC_{i,t}$ and $c_{feed,t}$, and $\theta_{i,t}$ is the measurement error. Equation (9) is a fixed effects model allowing us to account for the unobserved heterogeneity among firms. This adjustment allows for a more accurate representation of firm-specific influences that are not directly observable.

Substituting equation (9) into equation (5) yields the first-order condition (FOC) for cartel firms:

$$\frac{P - (c_{feed,t} + \gamma_i + \theta_{i,t})}{P} = -\frac{s_i^{car}}{\varepsilon^{car}} \tag{10}$$

where $\varepsilon^{car}$ is the elasticity of the residual demand facing the combined cartel firms, and

$s_i^{car}$ is the within-cartel market share of each firm. Rearranging the equation gives:

$$P(1 + \frac{s_i^{car}}{\varepsilon^{car}}) = c_{feed,t} + \gamma_i + \theta_{i,t} \tag{11}$$

We assume $E(\theta_{i,t}) = 0$, and it follows an AR(1) process. The FOCs are estimated using the panel data, whereas the market demand and the supply function of the competitive fringe are estimated with the time series data.

Table 6: Estimation Results for the FOC equation

| Variable | Coef. | St. Dev | P-value |
|---|---|---|---|
| $\gamma_{tyson}$ | 39.8048 | 10.8362 | 0.000 |
| $\gamma_{pilgrim}$ | 43.3303 | 11.2701 | 0.000 |
| $\gamma_{sanderson}$ | 52.3984 | 10.5703 | 0.000 |
| $\gamma_{perdue}$ | 51.6121 | 11.0729 | 0.000 |
| $\gamma_{koch}$ | 53.8619 | 10.6166 | 0.000 |
| $\gamma_{wayne}$ | 53.9437 | 11.0275 | 0.000 |
| $\gamma_{foster}$ | 53.9014 | 12.1478 | 0.000 |
| $\gamma_{harrison}$ | 54.3216 | 11.8542 | 0.000 |
| $\gamma_{simmons}$ | 54.0457 | 12.0147 | 0.000 |

Table 6 presents the estimated firm-level fixed effects. The results show that Tyson's estimated coefficient is the smallest, whereas Harrison's is the largest. Furthermore, all coefficients are statistically significant, indicating that the marginal costs for each firm are significantly greater than feeding costs. Using the coefficients from Table 6, along with the panel data enables the calculation of the annual marginal costs for each firm given in Table 7. The results show that there has been a general increasing trend in marginal costs across all companies over the two-decade period. One noteworthy trend is the inverse relationship between market share and marginal cost. The firm with the largest market share consistently demonstrates the lowest marginal costs, in line with with the theory.

Table 7: Estimated Marginal Cost

| | Tyson | Pilgrim | Sanderson | Perdue | Koch | Wayne | Foster | Harrison | Simmons |
|---|---|---|---|---|---|---|---|---|---|
| Marginal Cost (cents/pound) | | | | | | | | | |
| 2001 | 45.10 | 53.55 | 56.67 | 54.47 | 58.11 | 56.37 | 57.00 | 59.03 | 57.99 |
| 2002 | 41.52 | 50.46 | 53.52 | 51.33 | 54.52 | 53.25 | 54.40 | 55.51 | 55.09 |
| 2003 | 45.55 | 51.11 | 59.31 | 57.01 | 60.57 | 59.23 | 60.57 | 61.73 | 61.37 |
| 2004 | 57.54 | 63.14 | 71.33 | 68.90 | 72.74 | 71.45 | 72.39 | 73.83 | 73.36 |
| 2005 | 54.57 | 59.48 | 68.00 | 66.19 | 69.43 | 68.03 | 69.08 | 70.50 | 70.03 |
| 2006 | 45.09 | 42.60 | 60.58 | 57.68 | 62.05 | 60.66 | 62.90 | 64.12 | 63.71 |
| 2007 | 58.98 | 56.35 | 72.44 | 70.11 | 74.30 | 72.99 | 74.84 | 76.22 | 75.66 |
| 2008 | 62.84 | 61.73 | 74.99 | 73.57 | 77.58 | 76.31 | 78.00 | 79.43 | 78.67 |
| 2009 | 59.62 | 61.86 | 72.71 | 71.30 | 73.57 | 74.19 | 75.71 | 77.26 | 76.46 |
| 2010 | 64.71 | 68.55 | 77.84 | 76.79 | 78.67 | 79.35 | 80.71 | 82.49 | 81.51 |
| 2011 | 60.63 | 64.00 | 73.54 | 73.01 | 74.88 | 75.30 | 77.04 | 78.78 | 78.12 |
| 2012 | 69.02 | 71.86 | 81.14 | 80.84 | 81.48 | 83.27 | 84.71 | 86.69 | 85.98 |
| 2013 | 80.78 | 82.96 | 93.51 | 93.17 | 93.98 | 95.17 | 97.01 | 99.21 | 98.43 |
| 2014 | 86.75 | 90.24 | 98.89 | 98.51 | 99.34 | 100.27 | 102.20 | 104.36 | 103.56 |
| 2015 | 72.37 | 75.74 | 84.01 | 83.60 | 85.04 | 85.76 | 88.22 | 90.08 | 89.32 |
| 2016 | 66.15 | 69.50 | 77.24 | 77.35 | 78.65 | 79.68 | 82.25 | 83.94 | 83.27 |
| 2017 | 75.03 | 77.82 | 85.51 | 86.37 | 87.74 | 88.76 | 91.17 | 93.00 | 92.26 |
| 2018 | 75.83 | 82.02 | 88.90 | 90.11 | 91.68 | 92.67 | 95.18 | 97.04 | 96.27 |
| 2019 | 67.80 | 72.80 | 79.92 | 81.65 | 82.24 | 83.84 | 86.76 | 88.41 | 87.71 |
| 2020 | 52.19 | 56.81 | 63.90 | 66.28 | 66.66 | 68.29 | 71.58 | 72.91 | 72.33 |

Some companies consistently have higher marginal costs than others. For instance, Koch and Wayne typically exhibit higher costs compared to Tyson, which generally has lower costs throughout the period. The peak costs for most companies appear to occur between 2013

and 2015, after which there is a general decline or stabilization.

# 4 Stage-Game Profits

We start with calculating each cartel firm's stage-game profits[6] for all $t$,

$$\pi_{i,t} = (P_t - c_{i,t})\, q_{i,t} \tag{12}$$

in three different scenarios: $(\pi^M_{i,t}, \pi^N_{i,t}, \pi^D_{i,t})$. $\pi^M_{i,t}$ denotes the monopoly/collusion profit under the cartel agreement. Regarding the individual output levels, we assume the cartel agreed to use percentage quotas based on the member firms' within-cartel market shares in the pre-cartel period. These shares were applied to the collective output $Q_{car,t}$ and converted into sales allocations $\hat{q_{i,t}}$ of each member firm. $\pi^N_{i,t}$ is the static Nash equilibrium profit, and $\pi^D_{i,t}$ is an individual firms' optimal non-compliance profit. In case of deviation, a cartel firm can maximize its individual profit by discreetly increasing its own output beyond the allotted amount $(q_{i,t} > \hat{q_{i,t}})$, while the other members adhere to their quotas.

Based on the previous results in Section 3.2, we obtain the fringe supply function $Q_{fri,t} = b_0 + b_1 P_t + b_2 Feed_{t-7} + e_s t$ and the total demand function $Q^D_t = a_0 + a_1 P_t + a_2 P_{pork,t} + a_3 t + a_4 t^2 + D_m + e_t$. The estimation results give us $b_1 = 5.3004$, which means if the collusive firms restrict their output, the price will go up, and the competitive fringe will produce more. Having these two functions allow us to obtain the residual demand function $Q_{car,t} = Q_t - Q_{fri,t} = (a_1 - b_1)P_t + (a_2 P_{pork,t} + a_3 t + a_4 t^2 + D_m - b_2 Feed_{t-7}) + e_t - e_s t + a_0 - b_0 = (a_1 - b_1)P_t + \widetilde{X_t}$, where $\widetilde{X_t} = a_2 P_{pork,t} + a_3 t + a_4 t^2 + D_m - b_2 Feed_{t-7} + a_0 - b_0$ is the effective intercept at each time $t$. For simplicity, rewrite the equation as $P_t = -\frac{1}{a_1 - b_1}\widetilde{X_t} + \frac{1}{a_1 - b_1} Q_{car,t} = \alpha - \beta Q_{car,t}$. Each firm's marginal cost is defined as $c_{i,t} = c_{feed,t} + \gamma_i + \theta_{i,t}$, where $c_{feed,t}$ is the feed cost,

[6]It is important to note that the term "profit" used here does not refer to actual profit, but rather to quasi-profit or producer surplus. This distinction arises because the calculation is based on the difference between total revenue and total variable cost, owing to the unavailability of data on the fixed costs of each firm.

and $\gamma_i$ is the constant cost gap between firm $i$ and the feed cost.

First, let's consider the case where firms act as Cournot competitors with asymmetric costs, and derive the profit in Nash equilibrium $\boldsymbol{\pi_{i,t}^N}$. Firm $i$ chooses output $q_i$ to maximise its profit:

$$\pi_i^N = \max_{q_i}(\alpha - \beta Q_{car} - c_i)q_i \tag{13}$$

Solving firm $i$'s FOC, we obtain firm $i\prime s$ best response function as

$$q_i^N = \frac{\alpha - c_i}{\beta} - Q_{car} \tag{14}$$

Adding up equations 14 across n firms gives the expression for the total quantity supplied by the cartel:

$$Q_{car}^N = \sum_i q_i^N = \frac{n}{n+1}\frac{\alpha}{\beta} - \frac{1}{n+1}\sum_i \frac{c_i}{\beta} \tag{15}$$

If we define $\bar{c} = \frac{1}{n}\sum_i c_i$ as the average of marginal costs across all firms within the cartel and substituting $\bar{c}$ into Equation (14) and Equation (15) yields

$$\begin{aligned} Q_{car}^N &= \frac{n}{n+1}\frac{\alpha}{\beta} - \frac{n}{n+1}\frac{c_i}{\beta} = \frac{n}{n+1}\frac{\alpha - \bar{c}}{\beta} \\ q_i^N &= \frac{1}{n+1}\frac{\alpha}{\beta} - \frac{c_i}{\beta} + \frac{n}{n+1}\frac{\bar{c}}{\beta} \end{aligned} \tag{16}$$

The corresponding price is

$$P^N = \frac{1}{n+1}\alpha + \frac{n}{n+1}\bar{c} \tag{17}$$

firm $i's$ market share in a static Nash equilibrium is

$$s_i = \frac{q_i^N}{Q_{car}^N} = \frac{\frac{1}{n+1}\frac{\alpha}{\beta} - \frac{c_i}{\beta} + \frac{n}{n+1}\frac{\bar{c}}{\beta}}{\frac{n}{n+1}\frac{\alpha}{\beta} - \frac{n}{n+1}\frac{c_i}{\beta} = \frac{n}{n+1}\frac{\alpha - \bar{c}}{\beta}} \tag{18}$$

and therefore, the profit in Nash equilibrium $\boldsymbol{\pi_i^N}$ is

$$\pi_i^N = (P - c_i)\, q_i^N = (\ \frac{1}{n+1}\alpha + \frac{n}{n+1}\bar{c} - c_i\ )(\ \frac{1}{n+1}\frac{\alpha}{\beta} - \frac{c_i}{\beta} + \frac{n}{n+1}\frac{\bar{c}}{\beta}\ ) \tag{19}$$

Next, we consider the case where firms collude under asymmetric costs. In this setting, cartel members—or the cartel as a collective entity—behave akin to a monopolist, focusing on maximizing profits. The cartel's optimal production level is achieved when marginal revenue (MR) equals marginal cost (MC). However, due to varying costs among different firms, the selection of an appropriate MC for the cartel is critical. To maximize the utilization of available data, we employ a share-weighted average approach to ascertain the marginal costs of collusive firms. This method serves as the basis for estimating the marginal cost (MC) of the cartel.

From this premise, we are able to derive the following set of results:

$$\begin{aligned} Q^M &= \frac{\alpha - c_i^*}{2\beta} \\ P^M &= \frac{\alpha + c_i^*}{2} \\ q_i^M &= s_i Q^M \end{aligned} \tag{20}$$

where $c_i^*$ corresponds to the share-weighted average MC of collusive firms. Therefore, firm $i$'s collusive profit is:

$$\pi_i^M = s_i \frac{\alpha - c_i^*}{2\beta}(\frac{\alpha + c_i^*}{2} - c_i) \tag{21}$$

where its output quota is based on $s_i$.

Finally, we consider the case where firm $i$ tries to profitably deviate. A cartel firm can maximize its individual profit by discreetly increasing its own output beyond the allotted amount ($q_{i,t} > \hat{q_{i,t}}$), while the other members adhere to their quotas. Therefore, the total industry production now is $Q^D = q_i^D + (1 - s_i)\, Q^M = q_i^D + (1 - s_i)\, \frac{\alpha - c_i^*}{2\beta}$, and market price $P^D = \alpha - \beta Q^D = \alpha - \beta q_i^D - (1 - s_i)\, \frac{\alpha - c_i^*}{2}$. When firm $i$ maximizes its deviation profit by

choosing output,

$$\pi_i^D = \max_{q_i} \left( \alpha - \beta q_i - (1 - s_i) \frac{\alpha - c_i^*}{2} - c_i \right) q_i \tag{22}$$

the optimal result is given by

$$q_i^D = \frac{(\alpha - \hat{c})(1 + s_i) - 2\gamma_i}{4\beta} \tag{23}$$

# 5 The Stability of the Cartel

In this section, we delve into the dynamic implications of the (static) demand and cost estimates presented earlier. We introduce our repeated-game model, tailored to the internal structure of the broiler industry, and employ this dynamic model to quantify the firms' motivations for collusion.

In each month $t$, each cartel firm $i \in I$ observes the residual demand (both its slope $\frac{\partial P}{\partial Q_{car,t}}$, the effective intercept $\widetilde{X_t}$) and marginal costs $(c_{i,t})_{j \in I}$, and decides its own output $q_{i,t}$ conditional on its private information (which will be defined below). The total supply of collusive firms $Q_{car,t} = \sum_{i \in I} q_{i,t}$, fringe supply $Q_{fri,t}$, and the demand collectively determine the market price $P_t$.

The first thing to do is to decide the so called "detection lag", i.e. if one firm decides to deviate, how long would it take for other firms to realize that they have been cheated. The question becomes what are possible communication channels that would allow the cartel firms to cross-verify production figures. Various court documents reveal that the plaintiffs have frequently argued that leading poultry companies coordinate operations through membership in an industry benchmarking service, AgriStats. This service collects and disseminates a range of sensitive business data, including financial statements, production volumes, and sales data, which are accessible only to member firms who pay substantial subscription fees and contribute their data the pool.

Since Agristats releases monthly, quarterly and annual reports, the shortest monitor-

ing lag would be one month. Therefore, initially we assume the actual firm-level outputs are perfectly observable with $L = 1$ period lag $\left((q_{i',\tau})_{i' \in I}, Q_{fri,\tau}\right)_{\tau \leq t-L-1}$ ($i'$ refers to firms within the cartel other than firm $i$). Under this assumption, firm $i$'s private information at the beginning of month $t$ contains its own production to the current month, and the production of other cartel firms and the competitive fringe with 1 month lag: $h_i^t = \left(q_{i',\tau}, Q_{fri,\tau})_{i' \in I, \tau \leq t-2}, q_{i,t-1}, (P_\tau)_{\tau \leq t-1}\right)$. Furthermore, the information accessible to the general public is delineated as the following information set: $h_t = \left(q_{i',\tau}, Q_{fri,\tau})_{i' \in I, \tau \leq t-2}, (P_\tau)_{\tau \leq t-1}\right)$. For cartel firms, we assume they hold static expectations about fringe output, which means they expect $Q_{fri,\tau} = Q_{fri,t-2}$ for each $\tau \geq t$, since cartel firms had limited information about the production of fringe supply. In addition, it is presupposed that the evolution of demand and costs constitutes common knowledge for all cartel firms. Consequently, the effective intercept $\widetilde{X_t}$, the slope of residual demand ($a_1$, $b_1$) and the marginal costs are universally recognized by all firms involved.

Consider the following equilibrium based on trigger strategies. The cartel firms are supposed to supply their respective quota allocations $\hat{q_{i,t}}$, given the information they have. Non-compliance is detected in period $\tau$ if, given the quarterly statistics, it becomes common knowledge that some firm did not produce its quota for the first time. Therefore, in each month $t$, given the expectation formed at $t$, the firms agree to play the following strategy for $\tau \geq t$:

- If compliance is confirmed before month $t$, in other words, every collusive firm has adhered to their designated quota, then each firm will continue colluding and will consequently secure $\pi_i^M$ indefinitely. Complying with the cartel agreement from month t on gives firm $i$ the payoff of

$$V_{i,t}^M(r) = \frac{1+r}{r}\pi_{i,t}^M \tag{24}$$

  where $r$ represents an interest rate.

- Should any firm elect to deviate in pursuit of maximizing its profits, while others adhere to their quotas, it will secure a deviation profit until the deviation is detected. Given that non-compliance will be detected with a month delay, the deviating firm will accrue the deviation profit for this month. Consequently, the discounted gain from such deviation is $\pi_{i,t}^D$. Starting from the next month, as soon as the deviation is detected, all other firms will punish the deviating firm by reverting to the Nash equilibrium forever after, which gives us the discounted profits $\frac{1}{r}\pi_{i,t}^N$. Therefore when firm $i$ does not comply at time $t$, the optimal deviation payoff is

$$V_{i,t}^D(r) = \pi_{i,t}^D + \frac{1}{r}\pi_{i,t}^N \tag{25}$$

Therefore, in order for the "trigger strategy" to be an equilibrium, in each $t$, given $V_{i,t}^M(r)$ and $V_{i,t}^D(r)$, cartel stability requires that each firm's individual incentive to collude is positive. In other words, for the collusion to remain stable at $t$, all firms must anticipate positive payoffs at each point in the foreseeable future given the information at $t$. This disparity serves as the incentive constraint in our model.

$$\text{Incentive to collude}_{i,t}(r) = V_{i,t}^M(r) - V_{i,t}^D(r) \geq 0 \tag{26}$$

To accurately estimate each firm's incentive to engage in collusion, determining an appropriate discount factor is crucial. In our analysis, we adopt the monthly one-year Treasury rate. The computation of IC at each $t$ utilizes all the information available at $t$, some of it does not change over time (the estimated parameters of the demand equation and the firm-level quota $s_i$) where other pieces of information do change (discount rate, production levels $q_{it}$ and marginal costs $c_{it}$). The critical assumption here is that firms hold static expectations about the variables that change over time, for example at each time $t$ the discount factor $r_t$ will be applied for all future time periods.

Figure 2 provides a comparative analysis of three key price points: historical price data,

the theoretical cartel/monopoly price corresponding to $\pi_{i,t}^{M}$, and the Nash Equilibrium price corresponding to $\pi_{i,t}^{N}$ (based on actual demand, fringe supply, and cost profiles at each time period $t$). The shaded region from 2008 to 2016 corresponds to the collusion period as identified before. A closer look at the graph reveals some interesting patterns. Initially, the actual RTC price appears to closely align with the Nash Equilibrium price. A pivotal moment is observed at the inception of the cartel in 2008, where the prevailing market price is notably lower than the theoretical monopoly price. Subsequently, an interesting trend unfolds. There is a gradual alignment of the actual market price with the cartel's optimal price, with a convergence noted around the year 2010. This indicates a transitional period of approximately two years, during which the market dynamics were adapting to the cartel's strategic price-setting.

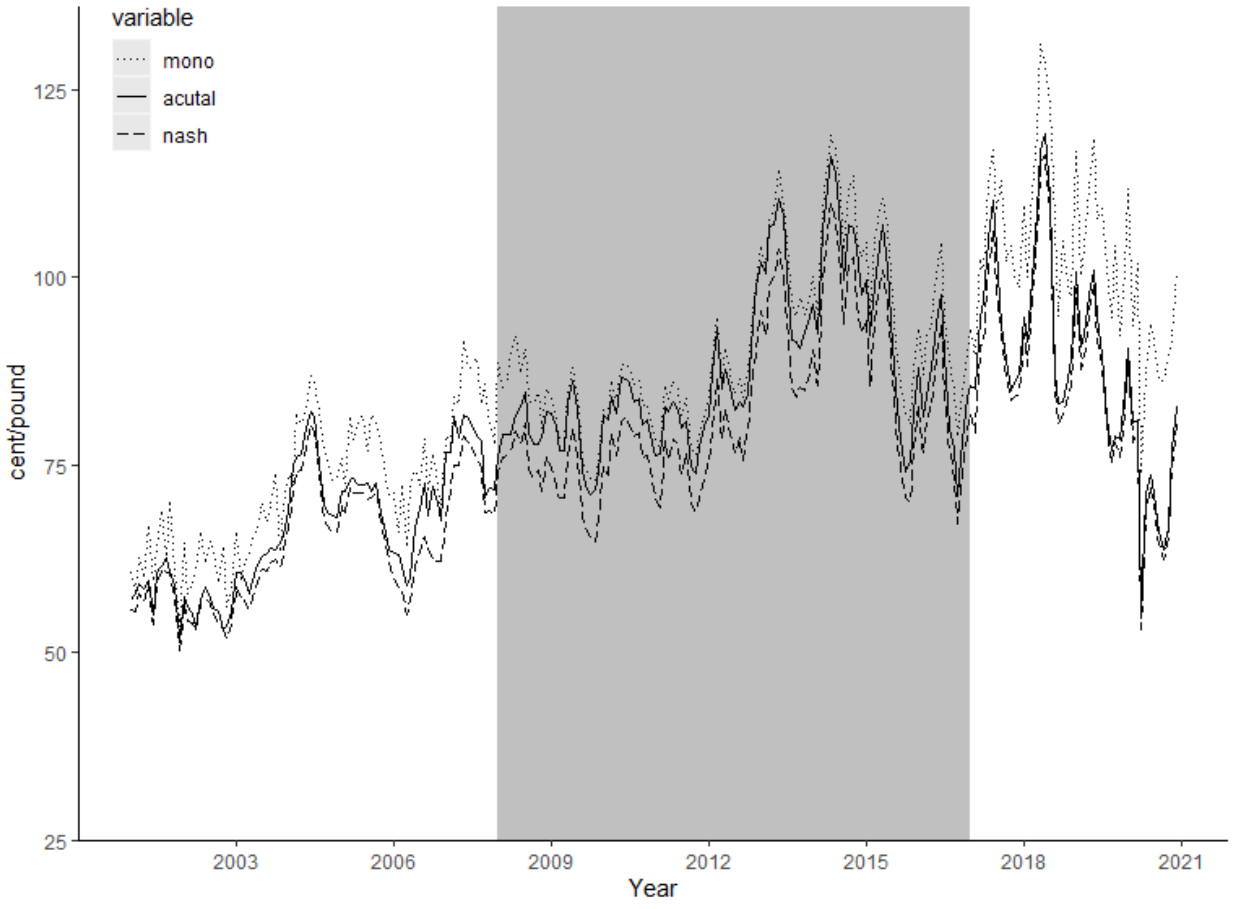



Figure 2: Actual and Monopoly Prices

A key factor influencing the observed transition in the broiler chicken market is the nature of its sales mechanisms. A notable portion of broiler sales—approximately 50-70%—occurs under customer contracts, with 10-20% happening on the spot market, and around 17-20% involving exports. Large-volume buyers, such as restaurants and grocery retailers, typically engage in annual or sometimes multi-year bidding and price negotiations. These negotiations, which are often facilitated by centralized buying cooperatives, occur towards the end of the calendar year and establish prices, discount levels, and other related terms for the upcoming year or even beyond.[7] These negotiations usually include commitments to weekly volumes between suppliers and customers. Such arrangements, while providing certain stability, significantly limit the firms' flexibility in adjusting production and revising selling prices over short periods. Following the public exposure of the activities of the broiler cartel in 2016, the price data also took around 1-2 years to diverge with the monopoly prices and come closer to the Nash equilibrium prices, indicating a return to a more competitive behavior or a change in market dynamics.

Figure 3 shows the incentive structure for collusion specific to Tyson, serving as a representative case. The graph illustrates the incentives to collude (ICCs) commencing at approximately \$6.2 billion, which then exhibits an upward trajectory. Notably, between 2008 and 2012, there is a discernible growth pattern, culminating in a phase of stability extending from 2012 to 2015. Subsequent to this period, a slight decline in the ICC is observed, followed by a phase of relative stability. Throughout the entire duration, the ICC consistently remains above \$6 billion. This persistence above the \$6 billion mark suggests that, according to our model, Tyson—a leading broiler firm—stands to gain more in discounted future profits by maintaining cooperation amongst firms to operate collectively as a monopoly[8] When placed in comparison with the ICCs of other firms, Tyson's ICC emerges

[7]More details of broiler contract are mentioned in the litigation document of IN RE BROILER CHICKEN ANTITRUST LITIGATION (Case No. 1:16-cv-08637).

[8]Referring to Tyson's Annual Reports on Form 10-K, the Operating Income for the chicken segment over fiscal years 2018-2020 were recorded at \$122 million, \$621 million, and \$866 million, respectively. Given that our ICCs represent the cumulative difference between discounted monopoly quasi-profits and quasi-profits of deviations from the current period onwards to infinity, an estimated magnitude of approximately \$6 billion

as the most substantial. This can be largely attributed to Tyson's position as the preeminent firm, enhanced by its advantage of incurring the lowest costs. Additionally, the arrangement of cartel quotas, aligned with the market shares prevalent prior to the formation of the cartel, distinctly benefits Tyson.

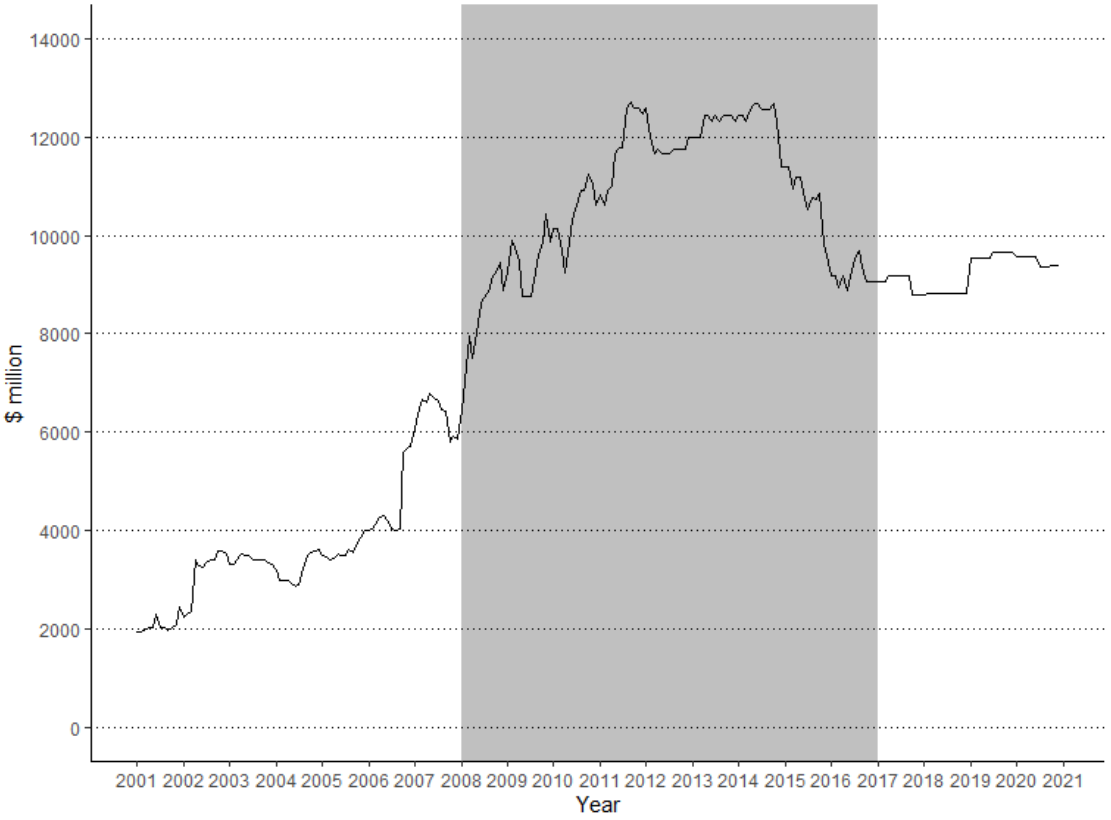



Figure 3: Tyson's Incentives to Collude
(beta=1-year Treasury Rate)

Figure 4 illustrates the collective incentive to collude, represented as the lower boundary of individual firm incentives. Consequently, this graph provides a more straightforward means to assess the cartel's stability over specified periods. The graph indicates that, up to the end of 2020, all collusive firms have a positive incentive to engage in collusion. This suggests that, in the absence of collusion detection, the cartel might have sustained its operations for an extended period. There is a clear upward trend in the values from 2008 to around the middle of 2015, which means during our defined collusion periods, all firms

appears to be reasonable.

have incentives to maintain the cartel instead of choosing to deviate. The peak occurs in 2015, after which there is a sharp decline. After the decline that bottoms out around 2016, the graph shows a period of relative stability with slight fluctuations yet maintaining a considerably high level. This persistence suggests that broiler firms continue to possess incentives for collusion, underscoring the need for oversight of collusion practices. Historical instances of collusion activities in the broiler industry further substantiate this assertion.

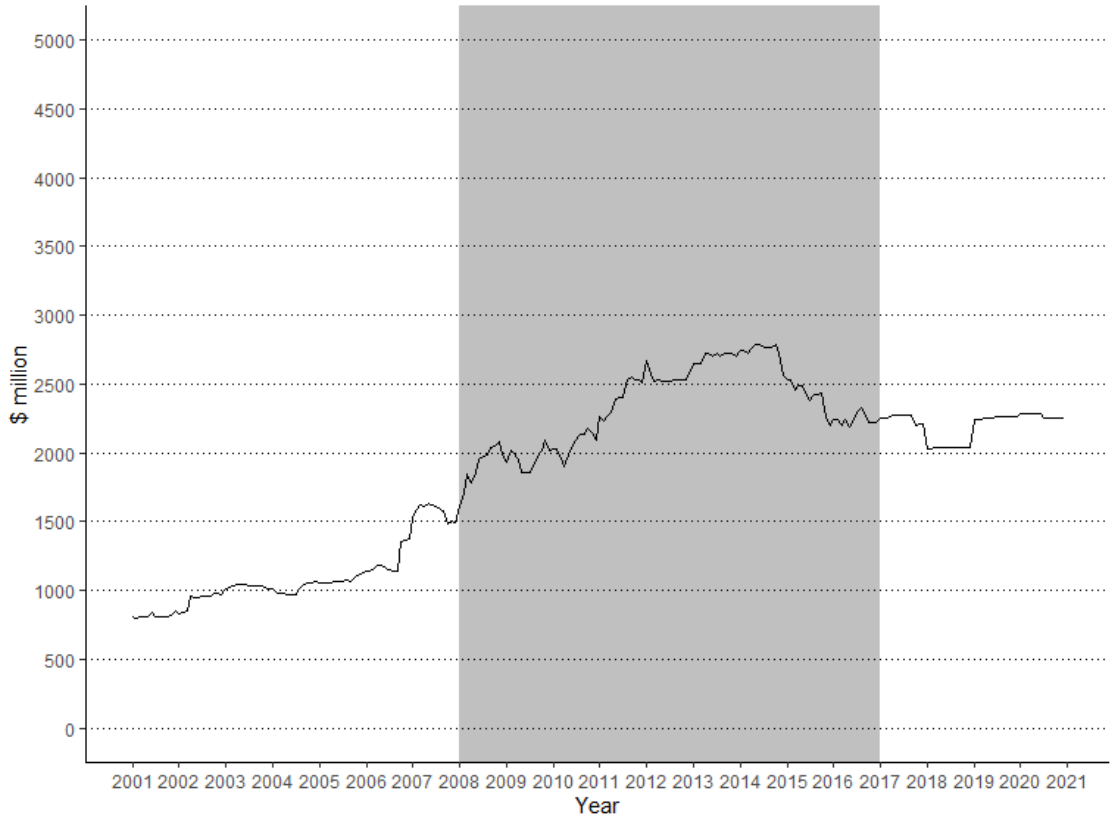



Figure 4: Collective Incentives = Lower Envelope of Individual Incentives
($\beta$ = 1-year Treasury Rate)

# 6 Sensitivity Analysis

The calculation of the IC for each firm depends on the length of monitoring (detection) lag $L$, the level of discount factor $\beta$, and each firm's profits in three different cases $(\pi_i^C, \pi_i^D, \pi_i^N)$ which in turn depend on the number of strategic firms versus the competitive firms. In this

section, we will examine the impact of these three factors and provide explanations for the nature of their influence.

**(1) Monitoring Lag**

Recall, that in the 'trigger strategy' equilibrium, punishment is deferred until non-compliance is confirmed after an $L$ month lag. This presupposes 'perfect' monitoring of production quantities with a delay based on some statistical reports as external verification sources for self-reported sales. Two pertinent questions emerge from this setup. First, why do firms opt to await production statistics rather than deducing rivals' non-compliance from current prices? The nature of the broiler industry offers a potential explanation. In this sector, it is common for companies to engage in pre-determined sales price contracts with retailers. According to lawsuit documents, approximately 50-70% of broilers are sold under customer contracts, 10-20% on the spot market, and about 17-20% are exported. Consequently, the current poultry price reflects a time lag due to these sales contracts, rendering real-time detection of deviations impractical.

Second, how sensitive are the results to the length of the detection lags? To answer this question we perform a sensitivity analysis by changing the length of the detection lag to three months and then to twelve months. These intervals coincide with AgriStats' quarterly and annual reports.

Figure 5 illustrates the collective incentives to collude with 1-month, 3-month, and 12-month lags. In comparison to the baseline collective incentive (the $L = 1$ line), which is represented by the solid line, is positioned above the $L = 3$ line. This suggests that a shorter monitoring lag correlates with a higher collective incentives to collude at any given time $t$. This outcome is logical, as more prompt monitoring implies that should a firm deviate, it would accrue less profit from such deviation. Referring to the incentives to collude equation, the subtracted term is smaller, leading to an increased calculated incentive to collude. Therefore, adherence to collusive quotas becomes more appealing to firms.

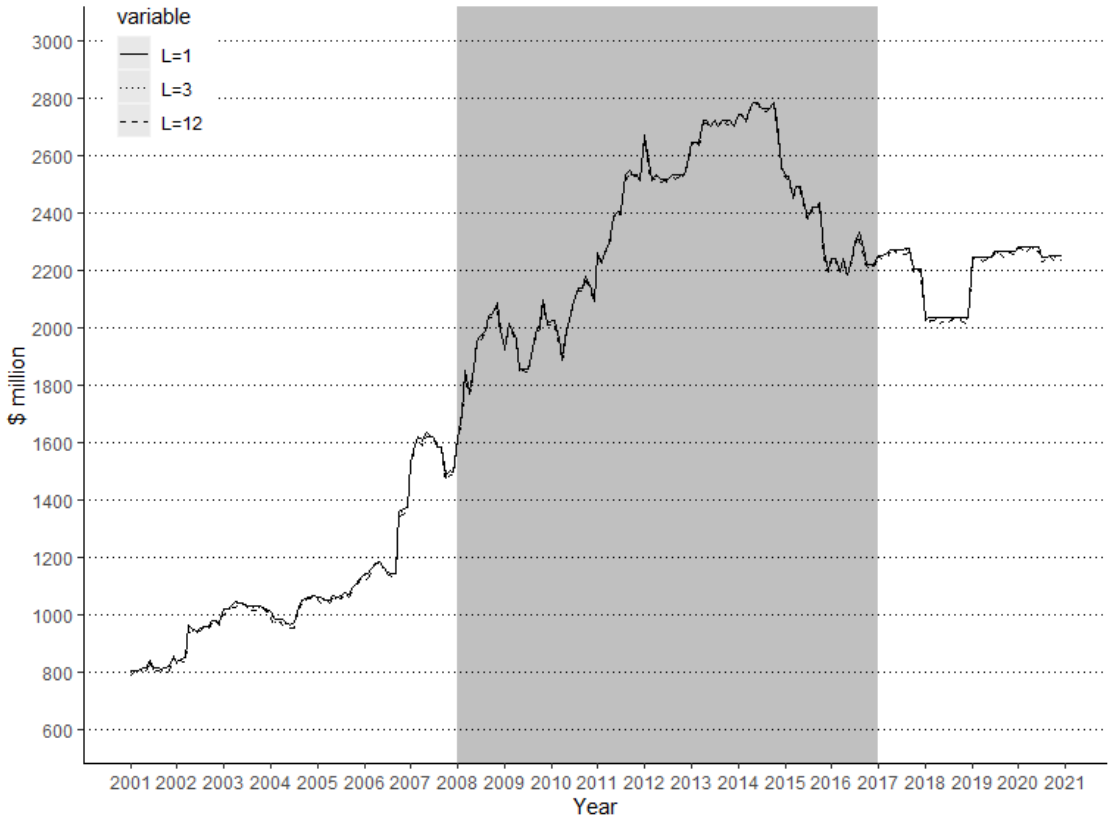



Figure 5: Collective Incentive to Collude with $L = 1$

The dashed line shown in Figure 5 depicts the collective incentives to collude with the 12-month lag. The line is situated below the collective incentive with a 3-month and 1-month lags. With an extended monitoring lag, a firm can accumulate deviation profits over an additional nine months, thereby enhancing the attractiveness of the deviation strategy. This is reflected by a reduced incentives to collude. Furthermore, the disparity between the two lines is more pronounced than the gap between $L = 3$ and $L = 1$ lines.

These findings provide some hints on the rationale behind firms' reliance on exchanging self-reported sales records despite the impending availability of more reliable data. Such communications, often referred as 'cheap talk,' can paradoxically facilitate collusion. Awaya and Krishna (2016) establishes conditions under which such cheap talk regarding past sales can enhance collusive profits, under the assumption that sales data remain confidential indefinitely. Spector (2022) further explores the role of cheap talk in scenarios where underlying

information is eventually made public, albeit with a delay.

**(2) Discount Factor**

In our base model, we utilize the monthly one-year Treasury rate to discount all future profits to the present period. It is worthwhile to experiment with alternative discount factors to assess their impact. Another frequently employed discount factor is based on the 10-year Treasury rate. Figure 6 offers insights into the historical trend of the 1-year and 10-year Treasury rates over the period extending from 2001 to 2020.




Figure 6: 1-Year Treasury Rate and 10-Year Treasury Rate

Both the 1-year and 10-year rates show fluctuating trends over the period. The 10-year rate tends to be higher than the 1-year rate, which is typical as longer-term bonds usually offer higher yields to compensate for the increased risk of holding them over a longer period. The two rates seem to move in a correlated fashion, with the 10-year rate generally mirroring the movements of the 1-year rate while at a higher level. Around 2020, there is a sharp decline, especially noticeable in the 10-year rate, which likely corresponds to the economic impact of the COVID-19 pandemic and the aggressive monetary policy response

aimed at supporting the economy. The 1-year rate shows more volatility and a sharper reaction to short-term economic changes, while the 10-year rate movements are smoother, reflecting longer-term economic outlooks and expectations.

During the 2019-2020 period, the 10-year Treasury rate experienced a decline, closely approaching and, for a brief duration, exceeding the 1-year Treasury rate. This occurrence, known as an inverted yield curve, holds considerable significance in economic analysis. Historically, it has served as a reliable predictor of an impending economic recession. It reflects investors' expectations for slower growth or a downturn in the future. When investors expect lower growth or a downturn, they demand higher yields for short-term investments due to perceived near-term risks and are willing to accept lower yields for long-term investments, anticipating a decrease in interest rates in response to weaker economic conditions.

According to Figure 7, the collective incentives to collude with the 10-year Treasury rate remains decidedly positive throughout the observed period, with values fluctuating between \$700 million and \$3 billion. This incentive witnesses an upward trajectory between 2000 and 2012, subsequently entering a phase of relative stability. Around 2015, a notable decrease is observed, yet the incentive stabilizes at approximately \$3 billion thereafter. When compared to the collective incentive derived using the 1-year Treasury rate, the magnitude of the collective incentives to collude with the 10-year Treasury rate is smaller due to higher yield and hence greater discounting of future profits.

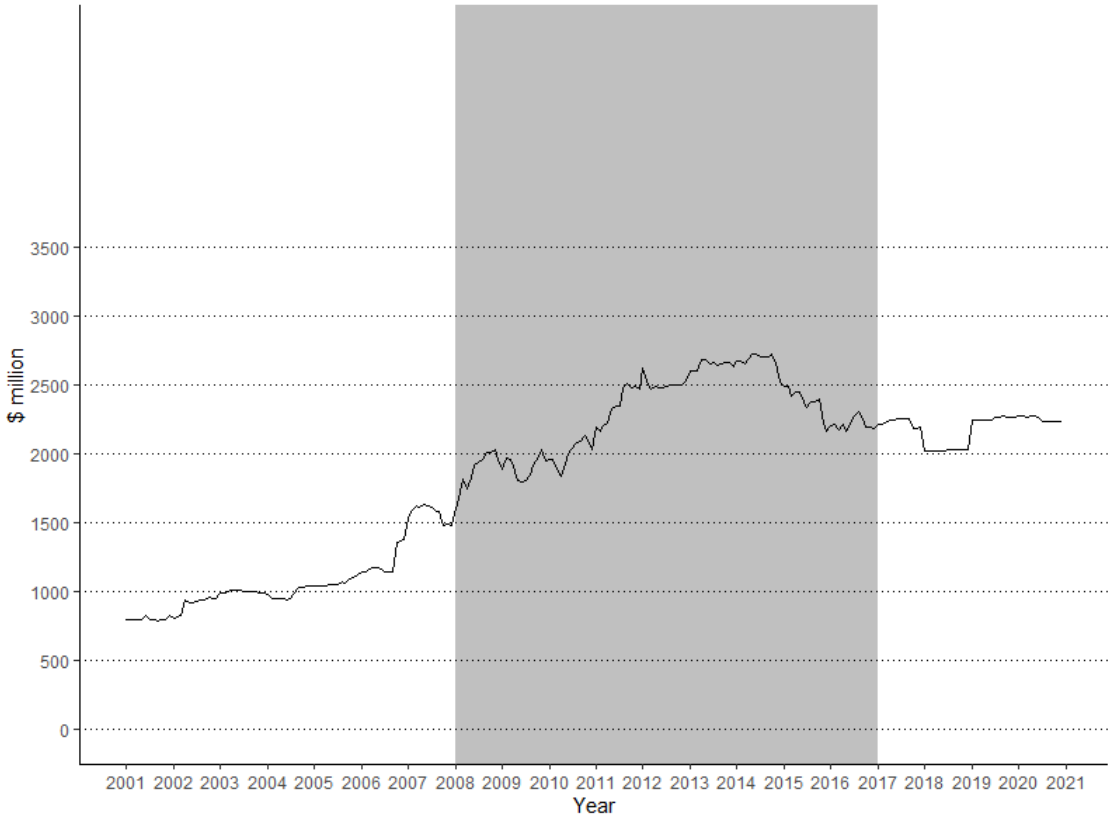



Figure 7: Collective Incentives to Collude with 10-Year Treasury Rate

**(3) Number of Cartel Firms**

The assessment of changing the number of participating firms in a cartel transcends the experimentation with varying monitoring lags and discount rates. The aforementioned parameters are incorporated only during the final phase of our analysis, specifically within the dynamic segment. Yet, redefining the cartel's composition concurrently alters the constellation of the competitive fringe, which in turn influences the estimation of the competitive fringe supply curve.

Given the fact that in our base model the cartel size was large (9 firms) it makes perfect sense to perform the sensitivity analysis using the model with fewer cartel members. A natural way to define the broiler industry cartel is to assume that it comprises of only the largest firms in the industry, which all happened to be publicly traded — Tyson, Pilgrim, and Sanderson Farms. The fact that they are publicly traded affords them another completely

legal line of communication and coordination via mandatory quarterly earnings calls.

Table 8: Estimation Results for Supply Function of the Competitive Fringe

| Variable | Coef. | Robust St. Dev | P-value |
|---|---|---|---|
| P | 17.0473 | 3.69717 | 0.000 |
| Feed_7 | -17.5447 | 4.79872 | 0.000 |
| Constant | 1056.466 | 201.0812 | 0.000 |
| Kleibergen-Paap rk LM statistic: 17.367 | | | |
| Chi-sq(1) P-val= 0.0000 | | | |
| Kleibergen-Paap rk Wald F statistic: 37.563 | | | |

Relative to the baseline model's estimations, the coefficient associated with the RTC price in the adjusted model is 1.5 times larger, yet it retains statistical significance. Additionally, the cost of feed from seven months prior exhibits a more pronounced effect on the supply from the competitive fringe. Nevertheless, when we compute the price elasticity of the competitive supply, the resultant figure is 0.3729. This value is closely aligned with the baseline model's elasticity of 0.3683.

Upon refining the supply function for the competitive fringe, we recompute the marginal costs for each firm and extrapolate the profits across three different scenarios. Based on the updated collective incentive for collusion graph presented in Figure 8, we can discern significant differences in the magnitude of the incentive to collude. In our original model, the incentive oscillates between \$1.4 and \$4.0 billion. In contrast, under the premise that the cartel is comprised exclusively of publicly traded broiler firms, the incentive to collude declines to a range of \$550 to \$620 million. This suggests a strategic impetus for including a broader spectrum of broiler firms within the cartel, which yields augmented benefits relative to a configuration constrained to publicly traded firms alone. Despite the diminished incentive in this setting, it consistently remains positive throughout the period, signifying that firms would benefit from adhering to their established quotas rather then deviate. In other

words, a cartel consisting of nine firms demonstrates more stability compared to one with only three firms. This increased stability is attributable to the collective market share commanded by the cartel. With nine firms, the cartel wields control over more than 50% of the market during the collusion period, thus enabling a more potent influence on industry-wide production levels. .

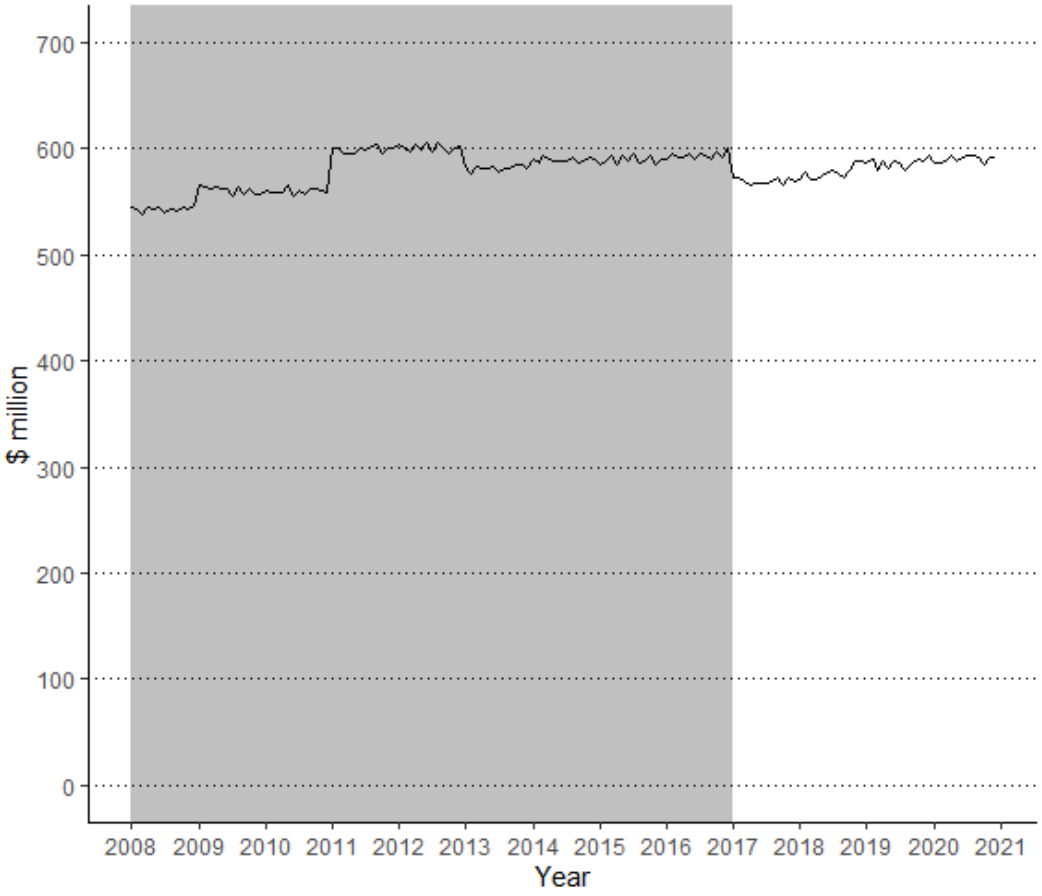



Figure 8: Collective Incentive to Collude with 3 collusive firms

# 7 Conclusion

Using the framework of repeated games, we investigate whether the U.S. broiler companies have the incentives to collude by fixing the quantities of broiler meat that they produce. Our analysis reveals that, throughout the alleged collusion period, broiler firms achieved higher collective discounted quasi-profits by cooperating rather than competing with each other. Moreover, this trend persists beyond the alleged timeframe of collusion, suggesting that the conditions incentivizing such collusion remained advantageous. This implies that, in the absence of the risk of being discovered, the involved companies would probably continue their collusive behavior beyond the supposed end of the collusion period.

By employing an industry model, we can estimate the price elasticity of demand and each firm's marginal costs, then calculate the prices, output quantities, and corresponding quasi-profits under various scenarios: Nash equilibrium, monopoly, and optimal deviation. By comparing these derived prices with actual market prices, we observe that during the collusion period, the actual prices more closely aligned with those predicted under monopoly conditions. This alignment suggests a potential for collusion.

We conceptualize the Incentives to Collude (ICCs) as the discrepancy between the collective discounted total profits derived from maintaining a monopoly stance and the profits from deviation. For the stability of a cartel, it is essential that ICCs maintain a positive value. Our empirical findings reveal that ICCs remains positive throughout the duration of the collusion period and extend beyond it.

To corroborate our findings, we conducted extensive sensitivity analyses employing alternative model specifications based on alternative discount factors, the duration of monitoring lags, and the composition of the alleged cartel group. All of those scenarios lead to the same conclusion.

Our findings open several pathways for future research. We anticipate that the analytical framework developed in this paper will prove beneficial for examining other markets with

similar characteristics. Moreover, there is potential to adapt this methodology to more complicated theoretical frameworks, including private monitoring and differentiated-products models. While these extensions may pose challenges, they are certainly feasible given the identification of appropriate empirical contexts.

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