Avian Influenza, Retail Pricing, and Loss-Leader Strategies: Causal and Structural Evidence from the Japanese Egg Market[*]

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Abstract

Highly Pathogenic Avian Influenza (HPAI) generates large and recurrent supply disruptions in egg markets, yet its implications for retail pricing behavior and competitive strategy remain poorly understood. This paper examines how retailers adjust prices, markups, and loss-leader incentives in response to HPAI using detailed retail scanner data from Japan between 2021 and 2024. We adopt a two-part empirical approach. First, we estimate the causal effects of HPAI on retail outcomes using an interactive fixed effects counterfactual estimator that accommodates staggered and transitory treatments. Focusing on Hokkaido, an almost closed market in terms of egg production and consumption, we find that HPAI leads to a gradual increase in retail prices but a persistent decline in retail markups and profits, with little change in quantities purchased. These patterns indicate incomplete pass-through of wholesale cost shocks and sustained margin compression at the retail level. Second, we develop and estimate a structural model of retail competition that combines a random-coefficients cross-nested logit demand system with Bertrand–Nash pricing. The model allows retailers to earn additional profits from cross-category purchases by egg buyers, capturing loss-leader incentives. Estimated demand elasticities imply profit-maximizing markups that are substantially higher than those observed in the data, providing strong evidence that egg pricing is shaped by loss-leader considerations rather than egg-category profits alone. We find that cross-category profits from egg buyers are economically large relative to direct egg margins and vary considerably across retail chains. Moreover, the intensity of loss-leader pricing declines following HPAI outbreaks, suggesting that supply disruptions limit retailers' ability to subsidize traffic-driving products. Together, our results highlight how supply shocks interact with retail competition and cross-category incentives, offering new insights into price adjustment and markup dynamics in grocery markets.

Keywords: Highly Pathogenic Avian Influenza, Egg Demand, Loss Leader Pricing, Causal Inference, Welfare

1 Introduction

Highly Pathogenic Avian Influenza (HPAI) is a recurring biosecurity shock that disrupts poultry supply chains through large-scale culling, movement restrictions, and heightened uncertainty about product availability and safety. In egg markets, such shocks translate into wholesale price spikes and downstream retail adjustments, with potentially large welfare consequences for consumers and retailers. Policy discussions often focus on producer compensation and supply recovery, yet the incidence of HPAI shocks critically depends on retail pricing and margin decisions, especially when retailers treat staple items such as eggs as strategic "traffic builders" rather than pure profit centers. A growing literature documents that the incidence of cost shocks depends critically on market structure and competitive conduct. In imperfectly competitive markets, pass-through is neither complete nor uniform, and cost increases can be absorbed by firms, shifted to consumers, or redistributed across the supply chain. Weyl and Fabinger (2013) provide a unifying theoretical framework that characterizes pass-through as a central object for incidence analysis under imperfect competition. Empirically, studies of food and grocery markets show substantial heterogeneity in pass-through across products and retail formats. Using U.S. data, Berck et al. (2009) demonstrate that commodity price shocks transmit imperfectly to retail food prices, with adjustment dynamics that reflect both cost structures and competitive conditions. These insights suggest that retail pricing behavior plays a pivotal role in shaping the welfare consequences of agricultural supply shocks.

Egg markets are particularly well suited for studying these mechanisms. Eggs are a staple food with relatively inelastic demand, a feature documented in structural and reduced-form demand studies (e.g., Bakhtavoryan et al., 2021). At the same time, eggs are a canonical example of a loss-leader product in grocery retailing. Retailers often price eggs aggressively to attract store traffic, anticipating profits from complementary purchases in other categories. A substantial marketing and industrial organization literature documents the prevalence and strategic role of loss-leader pricing in multiproduct retail settings (e.g., DeGraba, 2006; Li et al., 2013). When supply shocks raise wholesale costs, retailers face a trade-off between passing through higher costs to consumers and preserving the traffic-generating role of eggs. This trade-off implies that HPAI may compress retail margins even when wholesale prices rise, with ambiguous effects on retail profits and consumer welfare.

Recent agricultural economics research provides direct evidence that avian influenza outbreaks

affect retail prices and price premia in poultry markets. Zamani et al. (2024) show that avian influenza outbreaks in the United States lead to significant changes in retail price premiums for poultry products, highlighting heterogeneity across product types and market segments. Complementing this evidence, Wang and Ortega (2025) discuss the interaction between avian influenza, egg prices, and policy responses that balance biosecurity concerns with animal welfare objectives. These studies underscore that disease outbreaks have persistent and policy-relevant effects on retail prices, but they largely abstract from retailer strategic behavior and the role of loss-leader pricing. Existing work on HPAI has also emphasized upstream and aggregate market effects. For example, Huang et al. (2016) document that HPAI outbreaks significantly affect egg prices and production patterns in the United States, highlighting disruptions along the value chain. While these studies establish that HPAI has economically meaningful impacts, much less is known about how these shocks interact with retail pricing strategies and competitive behavior at the chain level. In particular, the role of loss-leader pricing in mediating the transmission of HPAI shocks to consumers remains largely unexplored.

This paper contributes to the literature by providing a retail-focused analysis of HPAI that combines causal inference with structural modeling. We study the Japanese egg market between January 2021 and June 2024, a period characterized by multiple HPAI outbreaks affecting different regions at different times. Our analysis proceeds in two complementary parts. First, we estimate the causal effects of HPAI on retail prices, quantities, markups, and profits using the Interactive Fixed Effects Counterfactual (iFEct) estimator (Liu et al. (2024)), which is well suited to settings with staggered and temporary treatments. This reduced-form analysis establishes how retail outcomes respond to HPAI without imposing strong structural assumptions. Second, we develop and estimate a structural model of demand and retail pricing to interpret these reduced-form effects. On the demand side, we estimate a random-coefficients cross-nested logit model that captures flexible substitution patterns across retail chains and geographic areas. On the supply side, we model retail pricing as static Bertrand–Nash competition (e.g., Kotschedoff and Liccardi, 2020) in which retailers internalize not only profits from egg sales but also cross-category profits generated by egg buyers. This framework allows us to quantify the extent to which eggs are priced below egg-category profit-maximizing levels and to recover the implied loss-leader profits.

A distinctive feature of our setting is the focus on Hokkaido. Hokkaido is nearly self-sufficient in egg production and consumption, which limits direct spillovers of local HPAI shocks to other regions. At the same time, wholesale prices formed in major mainland markets, especially Tokyo,

influence prices faced by retailers in Hokkaido. This asymmetric linkage allows us to construct credible counterfactuals using non-Hokkaido regions as controls while explicitly accounting for nationwide wholesale price movements. The combination of repeated HPAI events, geographic asymmetry, and rich retail data provides a rare opportunity to study both short-run causal effects and underlying pricing mechanisms.

Our results reveal a consistent pattern. The reduced-form analysis shows that HPAI does not significantly reduce retail quantities but leads to lower retail markups and profits, while retail prices increase only gradually. These findings suggest that retailers absorb a substantial portion of the cost shock rather than fully passing it through to consumers. The structural estimates confirm this interpretation. Demand for eggs is relatively inelastic, implying that egg-category profit maximization alone would call for much higher markups than those observed. Instead, retailers appear to rely heavily on cross-category profits, using eggs as a loss leader. Moreover, we find that loss-leader intensity declines following HPAI outbreaks, indicating that supply disruptions weaken retailers' ability or willingness to subsidize egg prices.

By linking causal evidence to a structural model of retail competition, this paper advances our understanding of how biosecurity shocks affect welfare through retail markets. Our findings complement existing work on pass-through, egg demand, and avian influenza, and provide new evidence on the retail-side mechanisms shaping the incidence of HPAI. More broadly, the results underscore that policies aimed at stabilizing food markets during disease outbreaks must account not only for producers and wholesale prices, but also for retail pricing strategies that critically influence consumer welfare.

The remainder of the paper is organized as follows. Section 2 describes the data and institutional background. Section 3 presents the reduced-form causal analysis using the iFEct estimator. Section 4 introduces the structural demand and supply model. Section 5 discusses the estimation strategy. Section 6 reports the empirical results and explores their implications for loss-leader pricing and welfare. Section 7 concludes.

2 Data

2.1 Retail Scanner Data

Our primary data source is transaction-based purchase data constructed from digitized receipts (CODE Data by Research and Innovation Co., Ltd.) provided by the Data Analysis Competition

2024 organized by the Joint Association Study Group of Management Science in Japan. The dataset aggregates household purchases of fresh products from receipts into a panel of purchasing outcomes. The sample period spans from January 2021 to June 2024. The underlying transactions are aggregated at the prefecture $\times$ day $\times$ retail chain level, with additional breakdowns by consumer demographics (e.g., gender and age) and product bar code information (e.g., egg size and pack count). Key variables include quantities purchased, number of purchasing customers, number of purchase occasions, expenditures, and modal (most frequently observed) price.

2.2 Supply-side and market covariates

We augment the purchase data with several supply-side and market variables. First, we compile information on highly pathogenic avian influenza (HPAI), including the timing and locations of outbreaks, egg production measures, and the number of birds culled from the Ministry of Agriculture, Forestry and Fisheries. Second, we obtain daily wholesale price data from industry sources (e.g., JA Zen-Noh and Hokuren). Third, we incorporate feed price indices from the Japan Egg Association as a proxy for cost pressure in egg production.

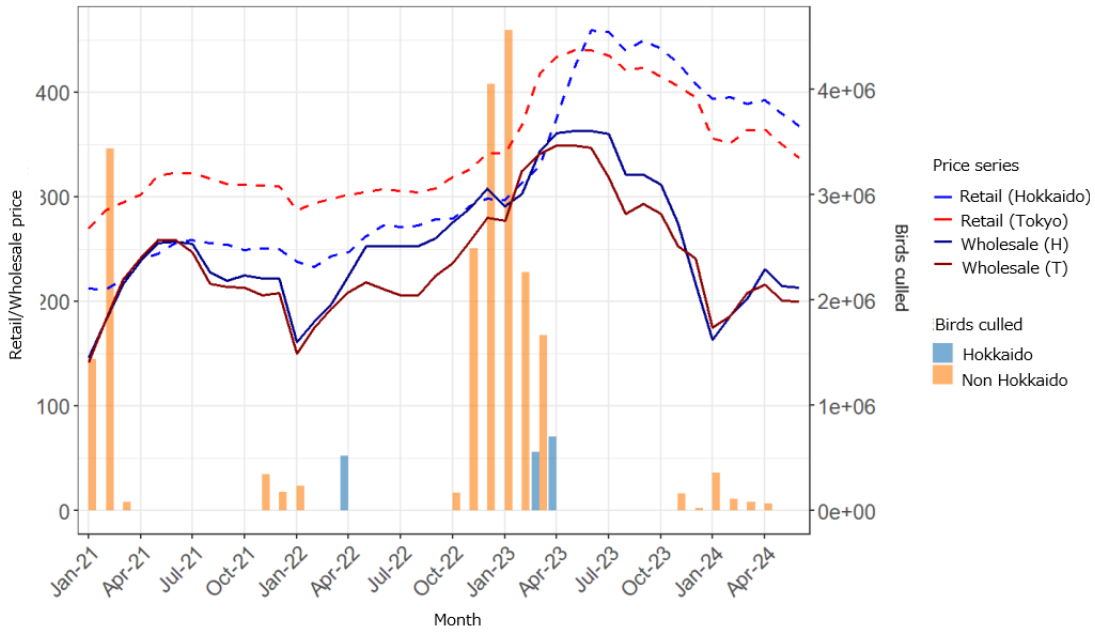
2.3 Why we focus on Hokkaido

A central challenge in studying HPAI shocks in retail egg markets is that production and consumption regions are often geographically separated. In many large prefectures (e.g., Tokyo and Osaka), a substantial fraction of egg supply is shipped in from outside, making it difficult to disentangle supply shocks, interregional trade, and retail pricing responses. We therefore focus on Hokkaido, where egg production and consumption are nearly closed within the region: the local production-to-consumption ratio is approximately 99%, and shipments to and from mainland Japan are limited. This feature provides a cleaner setting in which to interpret retail market outcomes as primarily reflecting shocks and adjustments within a geographically bounded market. Importantly, Hokkaido experiences multiple HPAI events during the sample period, enabling an analysis of repeated and potentially temporary disruptions.

2.4 Wholesale prices, retail prices, and culling dynamics

Figure 1 summarizes the evolution of retail and wholesale prices in Hokkaido and Tokyo along with culling intensity (the number of birds culled) in Hokkaido and mainland Japan. Two empirical patterns motivate our identification strategy. First, wholesale prices are highly correlated

Figure 1: Retail and wholesale price, # birds culled over time



nationwide, suggesting a strong common component in wholesale market conditions. In particular, wholesale price movements in Tokyo appear to transmit to Hokkaido, consistent with the presence of national pricing benchmarks and common cost shocks. This motivates including mainland (outside-Hokkaido) conditions as covariates when modeling wholesale and retail outcomes within Hokkaido.

Second, the effect of HPAI on wholesale prices appears asymmetric across space. Large culling events in mainland Japan coincide with sizeable changes in wholesale prices that may affect Hokkaido, whereas Hokkaido-specific HPAI events do not appear to shift Tokyo wholesale prices in the same way. This asymmetry is especially salient around April 2022, when a local HPAI-related disruption in Hokkaido is visible in Hokkaido series but does not generate a corresponding movement in the Tokyo wholesale series. This asymmetric linkage supports the use of non-Hokkaido prefecture–chain units as a comparison group in our reduced-form analysis. Specifically, while nationwide shocks (including mainland HPAI) may influence Hokkaido through wholesale market comovement, Hokkaido's own HPAI shocks are unlikely to spill over to other regions. Hence, concerns about violations of SUTVA through treatment spillovers from Hokkaido to the rest of Japan are limited, even though the converse direction (nationwide conditions affecting Hokkaido) remains relevant and is explicitly controlled for in the empirical strategy.

Table 1: Major retail chains in Hokkaido (volume share $\geq 1\%$)

Chain	Volume share	Avg. price (JPY/kg)	Avg. markup	Store coverage
The Big	12.7%	303.1	14.6%	Inside & outside Hokkaido
MaxValu	12.1%	327.7	19.5%	Inside & outside Hokkaido
AEON	11.4%	339.4	23.0%	Inside & outside Hokkaido
Super Arcs	8.9%	313.5	16.5%	Hokkaido only
Co-op Sapporo	7.8%	331.1	21.3%	Hokkaido only
TRIAL	4.2%	311.9	17.5%	Inside & outside Hokkaido
Daiichi	3.4%	296.6	8.5%	Hokkaido only
JR Fresh Market	3.0%	309.9	17.0%	Hokkaido only
Big House	2.8%	321.5	19.3%	Inside & outside Hokkaido
Ralse Mart	2.7%	319.9	18.3%	Hokkaido only
Sanchoku Fresh Market	2.5%	305.6	16.3%	Hokkaido only
Lucky (Hokkaido)	2.0%	321.9	17.9%	Hokkaido only
Seiyu	2.0%	354.8	27.1%	Inside & outside Hokkaido
Food Farm	1.9%	338.2	23.3%	Hokkaido only
Wholesale Supermarket	1.5%	262.9	2.2%	Hokkaido only
Tokou Store	1.3%	347.9	24.5%	Hokkaido only
Other	19.8%	310.1	15.7%	—

Note: Markup is defined as $(p - w)/p$, where p is the retail price and w is the wholesale price.

2.5 Retail chains in Hokkaido

To study loss-leader pricing incentives at the chain level, we construct a panel of major retail chains operating in Hokkaido. We restrict attention to chains with at least 1% share of egg purchase volume in Hokkaido. These chains jointly cover roughly 90% of the Hokkaido retail market in our purchase data, providing broad market coverage while allowing us to quantify substantial heterogeneity in pricing, margins, and geographic presence (Hokkaido-only versus both inside and outside Hokkaido). Table 1 summarizes market shares, average prices, average margins, and store coverage patterns across chains.

Finally, to discipline the structure of substitution patterns in the demand model, we compile detailed information on the geographic presence of each retail chain within Hokkaido. Table 2 reports whether each chain operates at least one store in each of five regions: the Sapporo metropolitan area, Central, Southern, Northern, and Eastern Hokkaido. This information plays a key role in the specification of the Random-Coefficient Cross-Nested Logit (RC-CNL) demand model in Section 4. In the CNL framework, each chain j can belong to multiple regional nests k, with membership weights α_{jk} capturing the strength of substitution within each region. Store presence data allow us to impose economically meaningful constraints on these membership weights. Specifically, if a chain does not operate any stores in region k, we restrict its membership weight to $\alpha_{jk} = 0$

Table 2: Store presence by region within Hokkaido (used to restrict CNL memberships)

Chain	Sapporo	Central	Southern	Northern	Eastern
The Big	O	O	O	O	O
MaxValu	O	O	O	O	O
AEON	O	O	O	O	O
Super Arcs	O	O	X	X	X
Co-op Sapporo	O	O	O	O	O
TRIAL	O	O	O	O	O
Daiichi	O	X	X	O	O
JR Fresh Market	O	O	X	X	X
Big House	O	O	X	X	X
Ralse Mart	O	O	X	X	X
Sanchoku Fresh Market	O	X	X	X	X
Lucky (Hokkaido)	O	O	O	O	O
Seiyu	O	X	X	X	X
Food Farm	O	O	O	O	O
Wholesale Supermarket	O	O	X	X	X
Tokou Store	O	X	X	X	X

Notes: This table records whether each chain operates stores in each region during our sample period. In the Random-Coefficient Cross-Nested Logit model explained in Section 4, we impose $\alpha_{jk} = 0$ if a chain has no stores in region k. Chains operating in only one region have fixed membership vectors (e.g., $(1, 0, 0, 0, 0)$), while chains operating in multiple regions have their nonzero α_{jk} estimated subject to $\sum_k \alpha_{jk} = 1$.

for that region. Chains operating in only one region therefore have fixed membership vectors (e.g., $(1, 0, 0, 0, 0)$), while chains operating in multiple regions have their nonzero α_{jk} parameters estimated from the data, subject to the normalization $\sum_k \alpha_{jk} = 1$. This approach substantially reduces the parameter space while preserving flexibility in substitution patterns across chains.

Importantly, because our purchase data are observed at the chain level rather than the store or regional level, regional demand is not directly observed. The store presence information thus provides a crucial bridge between observed chain-level shares and latent geographic competition. By combining observed price and share variation with these restrictions, the CNL model can infer latent competitive relationships among chains in a data-driven manner, rather than relying on an ex ante assignment of chains to nests. In the context of Hokkaido, where geographic distance and local shopping patterns are likely to shape substitution behavior, defining nests by region (Sapporo metropolitan area, Central, Southern, Northern, and Eastern Hokkaido) provides an economically interpretable structure that aligns with the spatial organization of retail markets.

3 Causal Effects of HPAI

To estimate the causal effects of Highly Pathogenic Avian Influenza (HPAI) on retail outcomes, we employ the Interactive Fixed Effects Counterfactual (iFEct) estimator (Liu et al., 2024). This approach is particularly well suited to our empirical setting for two reasons that are specific to the epidemiological and market features of HPAI outbreaks. First, HPAI outbreaks occur multiple times during our sample period and do not follow a single, once-and-for-all treatment pattern. Different prefectures experience outbreaks at different times, and some prefectures are affected more than once. The iFEct framework explicitly allows for staggered treatment timing, avoiding the well-known biases of two-way fixed effects estimators in such settings. Second, the economic effects of HPAI are inherently transitory. Once infected birds are culled and production recovers, the direct impact of an outbreak dissipates. In our context, treatment effects are therefore not permanent and can revert to zero over time. The iFEct estimator accommodates treatment reversal, allowing outcomes to return to their counterfactual paths after the treatment period ends. This feature is essential for modeling disease shocks such as HPAI, whose impacts are large but temporary.

The core idea of the iFEct approach is to estimate, using untreated units and pre-treatment observations, the counterfactual outcome that would have prevailed in the absence of treatment. The causal effect of HPAI is then obtained by comparing observed outcomes under treatment to these estimated counterfactuals. Formally, let $Y_{it}(0)$ denote the potential outcome for unit i at time t in the absence of HPAI. The counterfactual outcome is modeled as:

$$Y_{it}(0) = X_{it}'\beta + \alpha_i + \xi_t + \lambda_i' f_t + \varepsilon_{it}, \tag{1}$$

where i indexes units and t indexes time (month). The vector X_{it} contains observed covariates that vary at the unit-time level. The terms α_i and ξ_t denote unit fixed effects and time fixed effects, respectively, capturing time-invariant heterogeneity across units and common shocks over time. The term $\lambda_i' f_t$ captures unobserved time-varying heterogeneity through an interactive factor structure. Specifically,

$$\lambda_i' f_t = \sum_{k=1}^{r} \lambda_{i,k} f_{t,k},$$

where $f_{t,k}$ are latent common factors and $\lambda_{i,k}$ are unit-specific factor loadings. This structure allows unobserved shocks to affect units differentially over time, a feature that is particularly important in retail markets where chains may respond differently to aggregate demand or cost shocks. The

number of factors r governs the flexibility of the model. When $r = 0$, the specification reduces to a standard two-way fixed effects (TWFE) model. Rather than selecting r based solely on in-sample fit, we follow the iFEct procedure and choose r using cross-validation, evaluating out-of-sample prediction performance on hold-out samples. This approach balances flexibility and overfitting, and ensures that the factor structure captures meaningful unobserved heterogeneity.

We implement this framework in the following empirical setup. The unit of observation is a prefecture-retail chain pair, resulting in 762 units in total. Within each prefecture, we restrict attention to retail chains with at least a one percent share of egg purchases, which together account for approximately 90 percent of the market. The time dimension is monthly, spanning 42 months from January 2021 to June 2024. Treatment is defined as the occurrence of an HPAI outbreak in Hokkaido. We model treatment as a binary indicator that turns on at the outbreak date and remains active for 180 days, reflecting the period during which production disruptions and market adjustments are most pronounced. We assess robustness to alternative treatment windows and conduct carry-over tests to verify that estimated effects do not persist beyond the assumed treatment horizon. To account for broader market conditions, we include as covariates indicators for HPAI outbreaks in prefectures neighboring the four major wholesale markets outside Hokkaido, Tokyo, Nagoya, Osaka, and Fukuoka, also defined over a 180-day window. These controls capture nationwide supply shocks that may affect prices and quantities in Hokkaido through wholesale market linkages. Results are robust to alternative measures of treatment intensity, including the number of infected birds.

A remaining concern in our empirical design is whether prefecture-chain units outside Hokkaido constitute a valid control group for identifying the effects of HPAI outbreaks occurring in Hokkaido. In particular, one may worry about violations of the Stable Unit Treatment Value Assumption (SUTVA) if outbreaks in Hokkaido affect outcomes in other prefectures, or if shocks elsewhere feed back into Hokkaido. Institutional features of the Japanese egg market suggest that such concerns are limited and, importantly, asymmetric. On the one hand, Hokkaido is almost entirely self-sufficient in egg production and consumption, with local production accounting for nearly all eggs consumed within the prefecture. Interregional shipments of shell eggs between Hokkaido and the rest of Japan are minimal. As a result, HPAI outbreaks occurring in Hokkaido generate local supply shocks that are largely absorbed within the prefecture and do not directly affect retail prices or quantities in other regions. This implies that treatment does not spill over from Hokkaido to non-Hokkaido units, alleviating standard SUTVA concerns on the treatment side.

Table 3: Causal effects of HPAI using iFEct

Treatment period	180 days		90 days	
Variable	estimate	s.e.	estimate	s.e.
Retail Price (JPY/kg)	14.07**	4.17	4.60	4.56
Quantity Purchased (kg)	-39.29	669.0	-443.1	555.1
Retail Markup	-0.054**	0.018	-0.045**	0.016
Retail Profit (JPY)	-305,009**	110,572	-288,649**	122,451

Note: $**p < 0.01$; $*p < 0.05$; $+p < 0.1$.

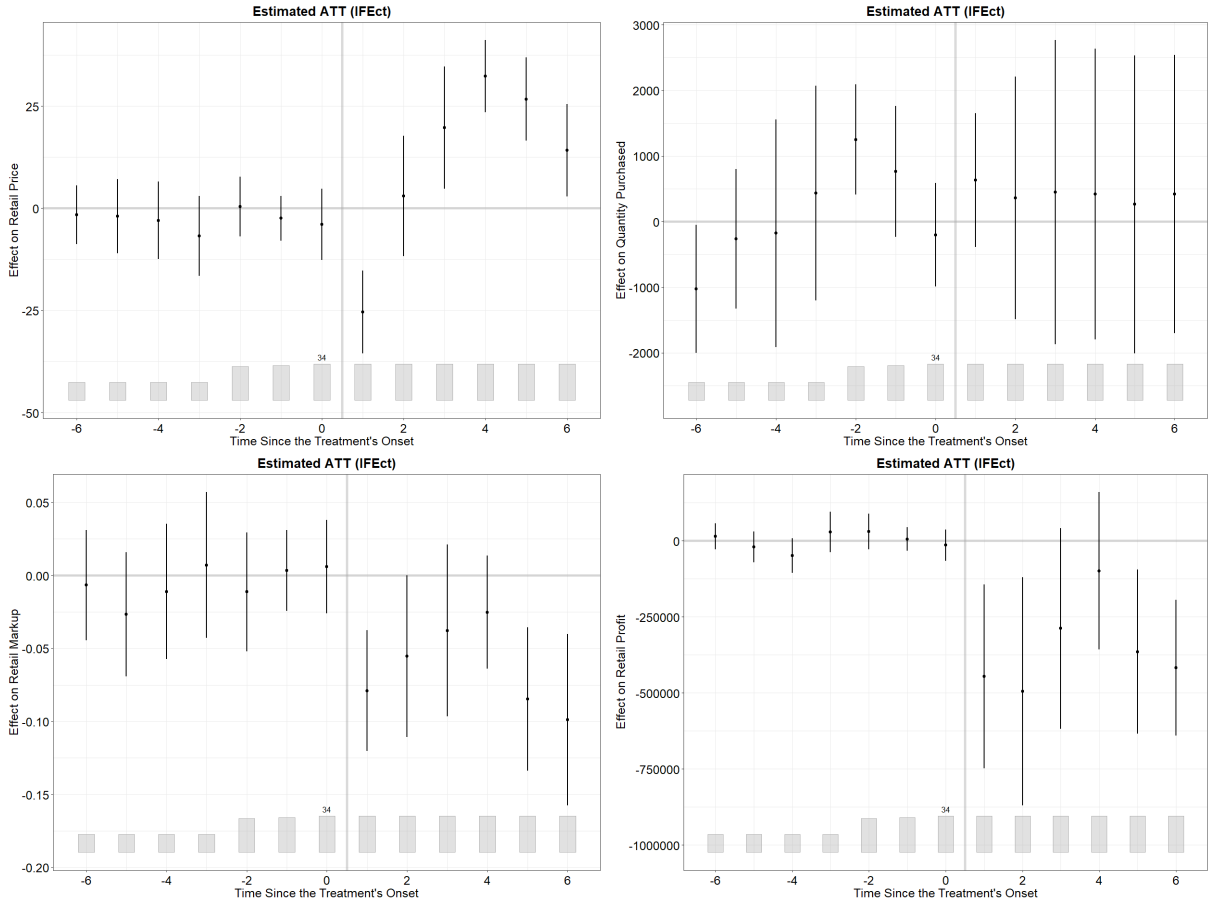
On the other hand, egg markets across regions are not completely independent. Wholesale prices formed in major markets, most notably the Tokyo market, serve as national benchmarks and can transmit nationwide supply conditions. Consequently, HPAI outbreaks occurring outside Hokkaido may affect wholesale prices faced by retailers within Hokkaido, even if Hokkaido-originating shocks do not propagate outward. This asymmetry implies that Hokkaido and non-Hokkaido units are not entirely unrelated, but rather linked through common national wholesale price dynamics. This feature strengthens, rather than weakens, the validity of using non-Hokkaido prefecture–chain units as controls. Because these units are exposed to nationwide shocks but not to the local Hokkaido treatment, they provide an informative counterfactual path for outcomes in Hokkaido in the absence of local HPAI outbreaks. In other words, non-Hokkaido units help trace the evolution of outcomes driven by common national factors, while the iFEct framework isolates the additional deviation attributable to local HPAI events.

To further account for nationwide supply shocks, our specification explicitly controls for HPAI outbreaks occurring near major wholesale markets outside Hokkaido. Together, these institutional considerations and controls support the use of non-Hokkaido units as a credible control group for identifying the causal effects of HPAI outbreaks in Hokkaido.

3.1 Results

We estimate treatment effects for several outcome variables: retail prices (measured in JPY per kilogram), quantities purchased (measured in kilogram), retail markups, and retail profits (in JPY). Together, these outcomes provide a comprehensive view of how HPAI affects market performance and welfare along the retail margin. Table 3 shows the estimation results and Figure 2 shows the event study plots for each of the outcome variables.

Figure 2: Causal effects of HPAI using iFEct: Event study plots



3.1.1 Retail Price

Table 3 reports the average treatment effects of HPAI on retail egg prices. When the treatment period is defined as 180 days, retail prices increase by approximately 14 JPY per kilogram, and the effect is statistically significant. In contrast, when the treatment window is restricted to 90 days, the estimated price effect becomes much smaller and statistically insignificant. This sensitivity to the treatment horizon suggests that the price response to HPAI is not immediate but unfolds gradually over time. Short-run price effects are muted, while medium-run adjustments become visible only when a longer post-treatment window is considered.

The event-study estimates in Figure 2 provide further insight into this dynamic pattern. Immediately following the onset of an HPAI outbreak, retail prices exhibit a temporary decline. This initial drop is followed by a gradual and persistent increase in prices over subsequent months. This pattern is consistent with retailers initially absorbing wholesale price increases or even temporarily lowering prices to maintain customer traffic during periods of heightened uncertainty. As supply constraints persist and wholesale prices remain elevated, retailers gradually pass through these cost increases to consumers. The event-study evidence therefore explains why average price effects are detectable over a 180-day horizon but not over a shorter 90-day window.

3.1.2 Quantity Purchased

Table 3 shows no statistically significant effect of HPAI on the quantity of eggs purchased, regardless of whether the treatment period is set to 180 or 90 days. Point estimates are small relative to their standard errors, indicating that aggregate retail demand for eggs remains largely unchanged following HPAI outbreaks. The event-study estimates corroborate this finding. Quantities purchased show no systematic deviation from their pre-treatment trends, and confidence intervals remain wide throughout the post-treatment period.

A plausible explanation for this null effect is that eggs are a staple good with relatively inelastic demand, making total consumption resilient to supply shocks and price fluctuations. Moreover, substitution across distribution channels may further dampen observed quantity responses. For example, declines in business-to-business demand or institutional purchases following HPAI may be offset by increased household consumption, leaving aggregate retail purchases largely unchanged. We explore these mechanisms further in the structural analysis.

3.1.3 Retail Markup

The estimated effects on retail markups are negative and statistically significant across both treatment horizons. Markups decline by approximately 5 percentage points following HPAI outbreaks, indicating that retailers do not fully pass through wholesale price increases to consumers. This result suggests that retailers absorb part of the cost shock rather than maintaining pre-outbreak margins. The event-study plots show that markups decline sharply immediately after the onset of HPAI and remain persistently lower throughout the post-treatment period. Unlike retail prices, markups do not exhibit a delayed recovery, indicating sustained margin compression.

This pattern is consistent with intensified price competition and the use of eggs as a loss leader during periods of supply disruption. Retailers appear to prioritize customer retention and store traffic over short-run margin preservation.

3.1.4 Retail Profit

Retail profits decline significantly following HPAI outbreaks. The estimated average effect corresponds to a reduction of approximately 300,000 JPY per month per chain, and the magnitude is similar across the 180-day and 90-day treatment windows. This result indicates that the decline in profits is both economically and statistically meaningful.

The event-study estimates reveal that retail profits drop sharply immediately after the onset of HPAI and remain depressed throughout the post-treatment period. While confidence intervals widen at longer horizons, the point estimates consistently indicate substantial profit losses. Taken together with the markup results, these findings suggest that retailers are unable to offset higher wholesale costs through higher prices or increased sales volumes. Instead, profit declines reflect sustained margin compression, consistent with loss-leader pricing behavior.

Taken together, the causal estimates reveal a coherent pattern. HPAI outbreaks do not materially affect quantities purchased but lead to lower retail markups and profits. Retail prices adjust only gradually, increasing in the medium run after an initial decline. These results suggest that retailers absorb a substantial portion of the supply shock, consistent with the strategic use of eggs as a loss leader. In the next section, we develop a structural model to quantify the underlying mechanisms and evaluate the welfare implications of this pricing behavior.

4 Model

4.1 Demand

A key ingredient of our structural analysis is a flexible demand system that can capture realistic substitution patterns across retail chains. A standard multinomial logit model imposes the Independence of Irrelevant Alternatives (IIA) property, implying counterfactually rigid substitution that is inconsistent with retail competition. A standard nested logit model relaxes IIA by allowing correlation within nests, but it requires the researcher to pre-specify a fixed nesting structure, i.e., each chain must belong to exactly one nest. In our setting, however, the relevant competitive groups are not known ex ante: chains operate in different geographic footprints, and their competitive overlap varies continuously across space.

We therefore adopt a random-coefficients cross-nested logit (RC-CNL) model. The CNL allows each retail chain to belong to multiple nests with chain-specific membership weights. This feature lets the data discipline competitive groupings through observed co-movements of prices and market shares, rather than forcing a researcher-chosen partition. In the context of Hokkaido, where geographic proximity is a natural determinant of competition, we define nests by five subregions and estimate the extent to which each chain competes within each subregion.

4.1.1 Nests and chain memberships

As we reported in Table 2, we define five geographic nests within Hokkaido: Sapporo metropolitan area, Central Hokkaido, Southern Hokkaido, northern Hokkaido, and Eastern Hokkaido. The purchase data are observed at the chain level (not separately by subregion), so we do not directly observe nest-level shares. Instead, we use store location information to parameterize each chain's exposure to each nest. Let $\alpha_{jk} \in [0,1]$ denote chain j's membership weight in region k. These weights satisfy

$$\sum_{k=1}^{5} \alpha_{jk} = 1 \quad \text{and} \quad \alpha_{jk} = 0 \text{ if chain } j \text{ has no stores in region } k. \tag{2}$$

For chains operating exclusively in a single region, the membership vector is known and fixed. For example, if a chain operates only in the Sapporo area, we set $\alpha_j = (1,0,0,0,0)$. For chains that operate in multiple regions, the remaining nonzero α_{jk} are estimated from the data, subject to the simplex constraint above. This structure allows the model to recover competition patterns that are more granular than those implied by a single, fixed nesting assignment.

Substitution strength within each region k is governed by a nest parameter $\mu_k \in (0, 1]$. Smaller values of μ_k imply stronger within-region correlation (i.e., greater substitutability among chains competing in the same region). The CNL nests the multinomial logit model as a special case (when $\mu_k = 1$ for all k) and includes standard nested logit specifications as special cases depending on the configuration of α_{jk}.

4.1.2 Utility function

Each period t, consumers decide whether to purchase eggs and, if so, from which retail chain. Consumer i's indirect utility from purchasing eggs at chain j is

$$u_{ijt} = X'_{jt}\beta + \gamma_i p_{jt} + \xi_{jt} + \varepsilon_{ijt}, \tag{3}$$

where p_{jt} is the retail price (JPY/kg), X_{jt} includes observed chain-time characteristics (e.g., chain dummies, year and month dummies, and HPAI dummy), ξ_{jt} captures unobserved demand shocks, and ε_{ijt} is an idiosyncratic taste shock. We allow for heterogeneous price sensitivity by assuming $\gamma_i \sim \mathcal{N}(\bar{\gamma}, \sigma^2_\gamma)$. The mean utility of the outside option (no purchase) is normalized to zero.

4.1.3 Market shares under RC-CNL

Let $\bar{u}_{ijt} \equiv u_{ijt} - \varepsilon_{ijt}$ denote utility net of the idiosyncratic shock. Define the inclusive value for nest k in period t as

$$IV_{kt} \equiv \sum_j \alpha_{jk}^{1/\mu_k} \exp\left(\frac{\bar{u}_{ijt}}{\mu_k}\right). \tag{4}$$

Then the CNL choice probability (and hence the predicted market share) for chain j in period t can be written as

$$s_{jt} = \int \frac{\sum_k \alpha_{jk}^{1/\mu_k} \exp\left(\frac{\bar{u}_{ijt}}{\mu_k}\right) IV_{kt}^{\mu_k - 1}}{1 + \sum_k IV_{kt}^{\mu_k}} \, dF(\gamma_i), \tag{5}$$

where $F(\gamma_i)$ is the distribution of heterogeneous price sensitivity. This expression highlights two distinct determinants of substitution: (i) geographic competitive overlap through α_{jk}, and (ii) within-region substitutability through μ_k.

4.2 Retail Competition and Loss-Leader Effects

We model retail pricing as a static Bertrand–Nash price competition among competing retail chains. In each period t, retailers observe the wholesale price of eggs and simultaneously choose retail prices, taking rivals' prices as given. Importantly, we allow retailers to consider not only

profits from egg sales themselves, but also additional profits generated by egg buyers through purchases of other products. This feature captures the role of eggs as a loss leader in grocery retailing.

4.2.1 Profit function

Let p_{jt} denote the retail price (JPY/kg) set by chain j in period t, and let p_{-jt} denote the vector of prices set by rival chains. Retailer j faces a wholesale price w_t, which is common across chains in a given period. Other marginal costs are assumed to be negligible relative to the wholesale price and are normalized to zero. The profit of retailer j is given by

$$\pi_{jt}(p_{jt}, p_{-jt}) = (p_{jt} - w_t)\, Q_{jt}(p_{jt}, p_{-jt}) \;+\; \lambda_{jt}\, Q_{jt}(p_{jt}, p_{-jt}), \tag{6}$$

where Q_{jt} is the quantity of eggs sold by chain j in period t, and λ_{jt} represents the marginal profit generated from other products by an additional egg buyer.

Egg demand is linked to the demand system described in the previous subsection. Specifically, we write $Q_{jt} = M_t s_{jt}$, where s_{jt} is the predicted market share from the demand model and M_t denotes market size, defined as the product of Hokkaido's population and per-capita egg consumption (kg per month).

4.2.2 Interpretation of λ_{jt}

The term $\lambda_{jt} Q_{jt}$ captures profits from cross-category purchases by consumers who buy eggs at chain j. By pricing eggs below the level that would maximize egg-category profits alone, a retailer may attract additional shoppers who generate profits through purchases of other grocery items. A key assumption in our baseline model is that marginal changes in egg demand translate one-for-one into changes in the number of egg buyers. Under this assumption, all variation in Q_{jt} reflects variation in store visits by egg purchasers, rather than changes in purchase intensity conditional on visiting. In practice, some egg purchases may be incidental to store visits motivated by other products. To the extent that this is the case, the estimated λ_{jt} should be interpreted as a lower bound on the true cross-category profit per egg buyer.

4.2.3 Retail pricing and equilibrium

Each retailer chooses p_{jt} to maximize π_{jt}, taking rival prices as given. The first-order condition for an interior optimum is

$$Q_{jt} + (p_{jt} - w_t + \lambda_{jt}) \frac{\partial Q_{jt}}{\partial p_{jt}} = 0. \tag{7}$$

Rearranging yields an expression for the loss-leader profit term:

$$\lambda_{jt} = -(p_{jt} - w_t) - Q_{jt} \left(\frac{\partial Q_{jt}}{\partial p_{jt}} \right)^{-1}. \tag{8}$$

This expression highlights how λ_{jt} is identified. Retail prices p_{jt} and wholesale prices w_t are observed in the data. The demand system provides estimates of $\partial Q_{jt}/\partial p_{jt}$, allowing us to recover the implied markup term $-Q_{jt}(\partial Q_{jt}/\partial p_{jt})^{-1}$ under the assumption of Bertrand–Nash equilibrium.

If retailers were maximizing profits from egg sales alone, λ_{jt} would equal zero (or be negative if additional marginal costs beyond the wholesale price were relevant). Positive estimates of λ_{jt} therefore provide direct evidence that retailers are willing to sacrifice egg-category margins in order to generate profits from complementary purchases, consistent with loss-leader pricing behavior.

4.2.4 Scope and limitations

Our modeling of loss-leader behavior is intentionally parsimonious. We abstract from dynamic pricing, consumer inventory behavior, and explicit modeling of cross-category demand. As a result, λ_{jt} should be interpreted as a reduced-form measure of the marginal profitability of egg buyers under the maintained assumptions. Extending the model to incorporate richer consumer shopping behavior and dynamic retailer decisions is an important avenue for future research.

5 Estimation Strategy

We estimate the random-coefficients cross-nested logit (RC-CNL) demand model using a Bayesian approach that builds on Jiang et al. (2009), extending their Bayesian random-coefficients logit framework (Berry et al., 1995) to a cross-nested structure. This approach allows us to jointly estimate heterogeneous consumer preferences, flexible substitution patterns, and endogenous prices within a unified likelihood-based framework. For a given draw of the nonlinear demand parameters, we recover the mean utilities ξ_{jt} by matching predicted market shares to observed shares. Specifically, we apply a contraction mapping that iterates on ξ_{jt} until the model-implied shares from the RC-CNL system equal the observed chain-level shares. This step generalizes the standard contraction in Berry et al. (1995) to the cross-nested logit setting.

Retail prices may be correlated with unobserved demand shocks ξ_{jt} due to retailers' pricing responses to local market conditions. To address this endogeneity, we jointly estimate a pricing

equation alongside the demand system. Specifically, we specify the following reduced-form price equation:

$$\ln p_{jt} = X'_{jt}\omega + Z'_{jt}\kappa + \nu_{jt}, \tag{9}$$

where X_{jt} includes observed demand shifters and fixed effects, Z_{jt} denotes a vector of instrumental variables, and ν_{jt} captures unobserved pricing shocks. Our instruments exploit cost shifters and competitive conditions that affect prices but are plausibly orthogonal to local demand shocks. Specifically, the instrument set includes: (i) wholesale egg prices in Hokkaido and Tokyo, (ii) feed prices faced by producers, and (iii) the average prices charged by chain j's competitors outside Hokkaido (or the national average price when a chain does not operate outside the prefecture). These variables shift marginal costs or competitive pressure but do not directly affect consumer utility conditional on controls. We allow (ξ_{jt}, ν_{jt}) to follow a joint normal distribution with covariance matrix Σ, which permits correlation between unobserved demand and pricing shocks. This structure ensures that price endogeneity is addressed within the likelihood rather than through moment conditions.

Estimation proceeds via Markov chain Monte Carlo (MCMC), drawing from the joint posterior distribution of demand parameters, price equation parameters, and the covariance matrix Σ. We run the sampler for 10,000 iterations, discard the first 5,000 draws as burn-in, and retain every 10th draw thereafter. This procedure yields 500 posterior draws used for inference. At each MCMC iteration, conditional on the sampled demand parameters, we recover ξ_{jt} via contraction mapping and evaluate the likelihood implied by the joint distribution of (ξ_{jt}, ν_{jt}). Posterior summaries for all parameters are computed from the retained draws. The retail supply-side parameter λ_{jt} is computed at each retained MCMC draw using the first-order condition derived in the previous section. Specifically, given observed prices, wholesale costs, and demand elasticities implied by the sampled demand parameters, we recover λ_{jt} as the value that rationalizes observed pricing behavior under Bertrand–Nash competition. This procedure yields a posterior distribution for λ_{jt} that fully accounts for uncertainty in demand estimation. All reported estimates of loss-leader profits are based on this posterior distribution.

Table 4: Demand estimates: utility function parameters

Parameter	Posterior Mean	Posterior SD
Price coefficient (mean), $\bar{\gamma}$	-0.007^{**}	0.0003
Price coefficient (sd), σ_γ	0.0038^{**}	6.1×10^{-6}
HPAI (Hokkaido), β_1	0.051^{*}	0.026
HPAI (outside Hokkaido), β_2	-0.186^{**}	0.054
Log number of fresh-food shoppers, β_3	0.176^{**}	0.026
Nest correlation: Sapporo area, $(1-\mu_1)$	0.650^{**}	0.001
Nest correlation: Central Hokkaido, $(1-\mu_2)$	0.172^{**}	0.002
Nest correlation: Southern Hokkaido, $(1-\mu_3)$	0.241^{**}	0.002
Nest correlation: Northern Hokkaido, $(1-\mu_4)$	0.231^{**}	0.002
Nest correlation: Eastern Hokkaido, $(1-\mu_5)$	0.194^{**}	0.003

Notes: ** and * indicate that zero is excluded from the 99% and 95% highest posterior density intervals, respectively. Chain, year, and month fixed effects are included but omitted for brevity.

6 Results

6.1 Parameter estimates

Table 4 reports the estimated preference parameters. The estimated mean price coefficient is negative and precisely estimated, confirming downward-sloping demand for eggs. The standard deviation of the price coefficient is also statistically significant, indicating substantial heterogeneity in price sensitivity across consumers. This heterogeneity is important for identifying substitution patterns and markup implications in the retail pricing model. In the next subsection, we will quantify the price elasticities at the chain-level and over time.

The estimated coefficients on HPAI indicators reveal an asymmetric effect. HPAI outbreaks occurring within Hokkaido have a small positive effect on utility, whereas outbreaks occurring outside Hokkaido significantly reduce utility. Taken together, the net effect of nationwide HPAI outbreaks is negative, implying a decline in consumers' willingness to pay for eggs. This pattern is consistent with heightened consumer concerns about food safety and supply disruptions at the national level, which outweigh any localized short-term effects within Hokkaido. The result aligns with the reduced-form evidence that HPAI ultimately depresses demand conditions faced by retailers. The coefficient on the log number of fresh-food shoppers is positive and statistically significant, confirming that variation in market size translates into higher chain-level demand, as implied by the aggregate demand framework.

The estimated nest correlation parameters reveal substantial geographic variation in competi-

Table 5: Estimated chain–region membership weights (α_{jk})

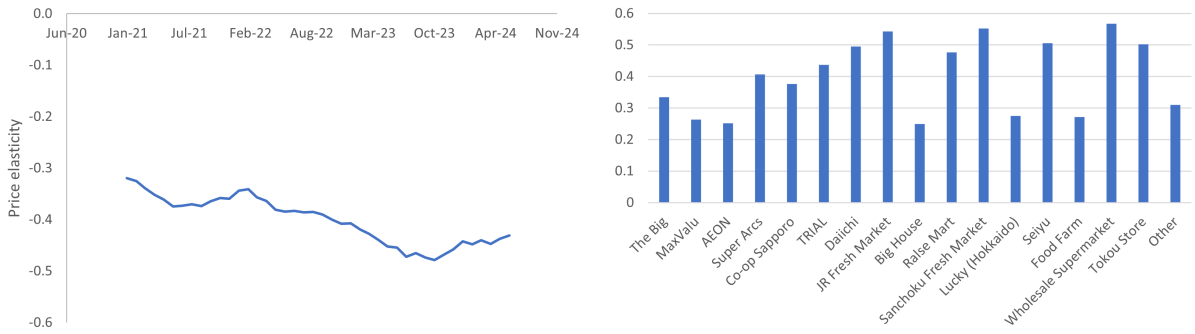
Chain	Sapporo	Central	Southern	Northern	Eastern
The Big	0.624	0.123	0.060	0.102	0.090
MaxValu	0.269	0.142	0.245	0.187	0.157
AEON	0.506	0.129	0.124	0.129	0.112
Super Arcs	0.803	0.197	0	0	0
Co-op Sapporo	0.788	0.037	0.051	0.062	0.063
TRIAL	0.872	0.031	0.030	0.019	0.048
Daiichi	0.950	0	0	0.026	0.024
JR Fresh Market	0.999	0.001	0	0	0
Big House	0.986	0.014	0	0	0
Ralse Mart	0.928	0.072	0	0	0
Sanchoku Fresh Market	1	0	0	0	0
Lucky (Hokkaido)	0.884	0.020	0.033	0.032	0.030
Seiyu	1	0	0	0	0
Food Farm	0.133	0.070	0.472	0.232	0.094
Wholesale Supermarket	0.990	0.010	0	0	0
Tokou Store	1	0	0	0	0
Other	0.429	0.124	0.187	0.139	0.121

Notes: α_{jk} measures chain j's exposure to region k in the cross-nested logit model. We impose $\alpha_{jk} = 0$ for regions where a chain has no stores, and estimate remaining weights subject to $\sum_k \alpha_{jk} = 1$.

tive intensity. The Sapporo metropolitan area exhibits the highest within-nest correlation, indicating that chains operating in this region are close substitutes and face intense competition. Other regions also display significant within-region correlation, but to a lesser extent. These estimates validate the use of a geographically structured demand model and highlight the importance of allowing substitution patterns to differ across regions.

Table 5 reports the estimated chain–region membership weights from the cross-nested logit model. These estimates provide a data-driven characterization of competitive overlap across geographic areas. Chains with localized store networks exhibit concentrated membership weights. For example, chains operating primarily in the Sapporo area have α_{jk} close to one for Sapporo and zero elsewhere, reflecting localized competition. In contrast, large multi-region chains display more dispersed weights, indicating meaningful competitive exposure across multiple regions. Importantly, these patterns emerge from observed price and share movements, rather than being imposed ex ante. This flexibility distinguishes the cross-nested logit from standard nested logit models with fixed group assignments and allows the model to capture heterogeneous competitive relationships across chains and regions.

Figure 3: Price elasticities by time and retail chain



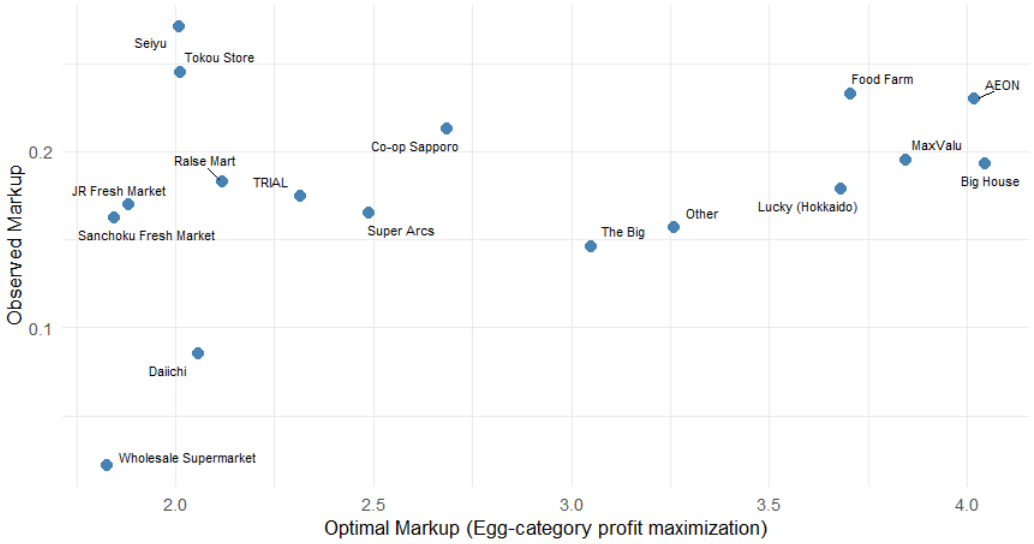
6.2 Price elasticities

We begin by summarizing the implied own-price elasticities from the estimated RC-CNL demand model. Across all chains and time periods, the average own-price elasticity is approximately -0.401. This magnitude indicates that demand for eggs at the chain level is relatively inelastic. The low elasticity has an important economic implication. If retailers were maximizing profits from egg sales alone, such inelastic demand would typically justify higher markups and higher prices. The fact that retailers do not raise prices aggressively, despite facing relatively inelastic demand, already suggests that pricing decisions are influenced by considerations beyond the egg category itself. This observation is consistent with the presence of loss-leader behavior, a hypothesis that we examine explicitly in the supply-side analysis.

The left panel of Figure 3 plots the evolution of the average own-price elasticity over time. The absolute value of the elasticity increases gradually over the sample period, indicating that demand has become more price sensitive in recent years. While the overall level of elasticity remains low, this trend suggests a gradual intensification of competition and substitution across retail chains. Notably, the timing of this increase coincides with repeated HPAI outbreaks and periods of elevated price volatility. These events may have heightened consumers' price awareness and willingness to substitute across chains, thereby making demand more elastic over time.

The right panel of Figure 3 reports average own-price elasticities by retail chain, measured in absolute value. There is substantial heterogeneity across chains. Large-format and discount-oriented retailers tend to exhibit higher elasticities, consistent with stronger competitive pressure and a more price-sensitive customer base. In contrast, chains with more localized operations or differentiated formats face less elastic demand. This heterogeneity reinforces the importance of modeling substitution patterns flexibly across chains. It also suggests that incentives to adopt

Figure 4: Optimal versus observed markups by retail chain



loss-leader pricing strategies vary systematically across retailers, a point we return to in the next subsection.

6.3 Optimal markups

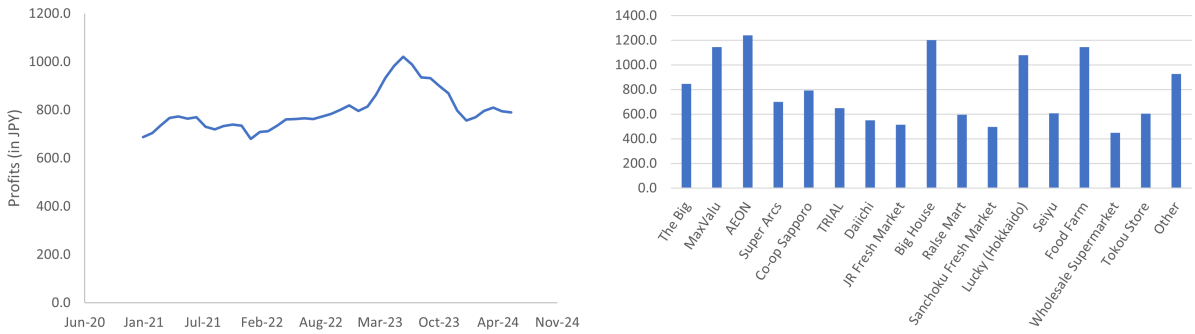
We next compare observed retail markups to the markups implied by the demand system under the assumption that retailers maximize profits from egg sales alone. Using the estimated own-price elasticities, we compute the profit-maximizing markup for each chain based on the standard static pricing formula,

$$\frac{p_{jt} - w_t}{p_{jt}} = -\frac{1}{\varepsilon_{jt}}, \tag{10}$$

where ε_{jt} denotes the own-price elasticity of demand. Using the average elasticity across chains and time periods ($\varepsilon \approx -0.40$), the implied optimal markup exceeds 2.5. Such a markup is theoretically infeasible in a standard pricing model, as it would require prices to be more than three times marginal cost. This calculation implies that observed prices are substantially lower than those that would maximize profits from egg sales alone.

Figure 4 plots, for each retail chain, the observed markup against the corresponding optimal markup implied by the demand estimates. Overall, observed markups are positively correlated with optimal markups. Chains facing less elastic demand tend to charge higher markups, indicating that pricing behavior responds in the expected direction to demand fundamentals. At the same time, the scatter reveals substantial dispersion around this positive relationship. In particular, several chains exhibit markedly different observed markups despite having similar optimal

Figure 5: Average λ_{jt} by time and retail chain



markups. Under a model in which retailers maximize profits solely from egg sales, such variation would be difficult to rationalize, as comparable demand elasticities should imply similar pricing incentives. This divergence is consistent with heterogeneity in loss-leader incentives across retailers. Chains that derive greater cross-category profits from egg buyers may optimally choose lower egg markups, even when their demand conditions are similar to those of other chains. In this interpretation, deviations below the optimal-markup benchmark reflect deliberate price reductions driven by loss-leader strategies rather than differences in demand or cost conditions. Importantly, the deviations are asymmetric: few chains set markups substantially above the profit-maximizing benchmark implied by the demand model. This pattern reinforces the view that observed pricing reflects downward adjustments relative to egg-category profit maximization, consistent with the use of eggs as a loss leader.

6.4 Loss-Leader Profits from Cross-Category Purchases

We now summarize the estimated loss-leader profit parameter, λ_{jt}, which measures the marginal profit generated from other product categories by an additional egg buyer. Throughout the paper, we interpret λ_{jt} as cross-category or bundled profit associated with egg purchases. Across all chains and time periods, the average estimated value of λ_{jt} is approximately 797 JPY per kilogram of eggs. This magnitude is economically large. For comparison, the average profit from egg sales implied by a positive retail markup is approximately 81 JPY per kilogram. Thus, the cross-category profit associated with egg buyers is an order of magnitude larger than profits earned from the egg category itself. This comparison highlights the central role of eggs as a loss leader in grocery retailing. Even modest increases in egg demand can generate substantial profits through complementary purchases, providing strong incentives for retailers to price eggs aggressively.

The left panel of Figure 5 plots the evolution of average loss-leader profits over time. The

figure shows a noticeable increase in λ_{jt} following the onset of HPAI outbreaks. This pattern suggests that the composition or behavior of egg buyers may have changed after repeated supply disruptions. One possible interpretation is that HPAI altered the characteristics of consumers purchasing eggs, for example by increasing the share of shoppers who bundle egg purchases with larger grocery baskets. Alternatively, heightened price competition during supply shocks may have increased retailers' reliance on eggs as a traffic-driving product. While disentangling these mechanisms is beyond the scope of the current model, the temporal pattern is consistent with a strengthening of loss-leader incentives following HPAI outbreaks.

The right panel of Figure 5 reports average values of λ_{jt} by retail chain. Loss-leader profits vary substantially across retailers. Some chains exhibit very large values of λ_{jt}, indicating a strong reliance on cross-category profits from egg buyers, while others display more modest values. This heterogeneity likely reflects differences in store formats, product assortments, and customer shopping behavior. Chains with broader assortments or a stronger focus on one-stop shopping may extract greater complementary profits from egg purchasers, whereas more specialized retailers may face weaker cross-category linkages.

Taken together, the magnitude, time variation, and cross-chain heterogeneity of λ_{jt} provide strong structural evidence that egg pricing cannot be understood solely through egg-category profit maximization. Instead, retailers' pricing decisions reflect a broader profit calculus that incorporates cross-category demand, consistent with loss-leader pricing behavior.

6.5 Changes in Loss-Leader Intensity Following HPAI

We next examine how loss-leader behavior changes following HPAI outbreaks by focusing on the loss-leader profit rate, defined as the ratio of cross-category profit to the retail price, λ_{jt}/p_{jt}. Using the first-order condition from the retailer pricing problem, this object can be written as

$$\frac{\lambda_{jt}}{p_{jt}} = -\frac{1}{\varepsilon_{jt}} - \frac{p_{jt} - w_t}{p_{jt}}, \tag{11}$$

which highlights that the loss-leader profit rate corresponds to the gap between the profit-maximizing margin implied by demand elasticities and the margin actually observed in the data. We evaluate how this loss-leader profit rate changes following HPAI outbreaks. Across all retail chains, the loss-leader profit rate declines after the onset of HPAI. This pattern indicates that the divergence between observed pricing and the benchmark implied by egg-category profit maximization becomes smaller.

Figure 6: Absolute percentage change in loss-leader intensity following HPAI, by retail chain

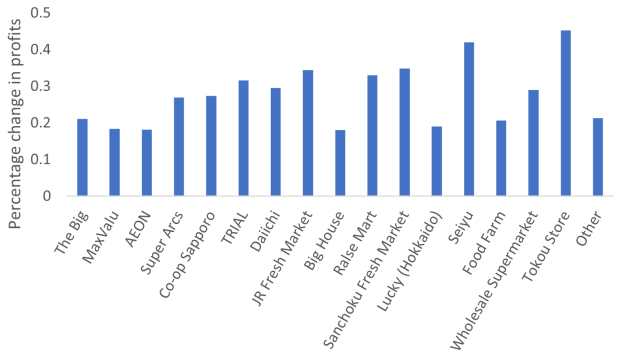


Figure 6 plots the absolute change in the loss-leader profit rate for each chain. The magnitude of the change varies substantially across retailers, suggesting heterogeneous responses to HPAI. Chains experiencing larger declines in λ_{jt}/p_{jt} appear to move closer to egg-category profit maximization, consistent with a reduced reliance on loss-leader pricing. Importantly, a decline in the loss-leader profit rate does not imply that retailers abandon loss-leader strategies altogether. Rather, it suggests a partial adjustment away from aggressive loss-leader pricing. One plausible interpretation is that HPAI alters the composition or behavior of egg buyers, reducing the expected cross-category profit generated by each additional egg purchase. Alternatively, supply disruptions and higher wholesale prices may limit retailers' ability to subsidize egg prices, even when loss-leader incentives remain present.

Taken together, these results indicate that HPAI not only affects retail prices and margins directly, but also reshapes retailers' broader pricing strategies by attenuating the intensity of loss-leader behavior.

7 Conclusion

This paper studies the market and welfare implications of highly pathogenic avian influenza (HPAI) in Japan with a focus on retail pricing behavior in the egg category. Using receipt-based scanner data linked to outbreak and supply-side information, we document economically meaningful downstream impacts of HPAI in Hokkaido. Reduced-form estimates using an interactive fixed-effects counterfactual framework show that HPAI is associated with higher retail prices over a medium-run horizon but lower retail markups and lower retail profits, indicating incomplete pass-through and margin compression.

To interpret these patterns, we develop and estimate a structural model that combines an RC-

CNL demand system with a Bertrand–Nash pricing framework that allows for cross-category (loss-leader) profits from egg buyers. The structural estimates imply low average own-price elasticity at the chain level, which would normally predict high category-optimal markups. Instead, observed markups are far below the profit-maximizing benchmark, and the implied cross-category profit term is large and heterogeneous across chains. Moreover, measures of loss-leader intensity change around HPAI episodes, suggesting that biosecurity shocks can reshape retailer incentives beyond the egg category itself.

Our analysis has several limitations that motivate future work. First, λ_{jt} is a reduced-form object inferred from pricing optimality and demand elasticities; without explicit basket-level purchase data, it cannot be cleanly decomposed into visit frequency, basket size, or category-specific complementarities. Second, the pricing model is static and abstracts from dynamic promotions, inventory constraints, and forward-looking behavior during prolonged supply disruptions. Third, while focusing on Hokkaido improves interpretability, it naturally raises external-validity questions for regions with stronger interregional trade. Extending the framework to jointly model spatial reallocation and retail competition, and validating λ_{jt} using basket-level or store-visit data, are promising directions for future research.

References

R. Bakhtavoryan, V. Hovhannisyan, S. Devadoss, and J. Lopez. An empirical evaluation of egg demand in the united states. *Journal of Agricultural and Applied Economics*, 53(2):280–300, 2021.

P. Berck, E. Leibtag, A. Solis, and M. Villas-Boas. Patterns of pass-through of commodity price shocks to retail prices. *American Journal of Agricultural Economics*, 91(5):1456–1461, 2009.

S. Berry, J. Levinsohn, and A. Pakes. Automobile prices in market equilibrium. *Econometrica : journal of the Econometric Society*, 63(4):841–890, 1995.

P. DeGraba. The loss leader is a turkey: Targeted discounts from multi-product competitors. *International Journal of Industrial Organization*, 24:613–628, 2006.

W. Huang, J. Todd, and Y. Wang. Impact of highly pathogenic avian influenza on US table egg prices. *Choices*, 31(2), 2016.

R. Jiang, P. Manchanda, and P. E. Rossi. Bayesian analysis of random coefficient logit models using aggregate data. *Journal of Econometrics*, 149(2):136–148, 2009.

M. Kotschedoff and G. Liccardi. Higher minimum quality standards and redistributive effects on consumer welfare. *Journal of Public Economics*, 190:104260, 2020. doi: 10.1016/j.jpubeco.2020.104260.

X. Li, B. Gu, and H. Liu. Price dispersion and loss-leader pricing: Evidence from the online book industry. *Management Science*, 59(6):1290–1308, 2013.

L. Liu, Y. Wang, and Y. Xu. A practical guide to counterfactual estimators for causal inference with time-series cross-sectional data. *American Journal of Political Science*, 68(1):160–176, 2024.

H. H. Wang and D. L. Ortega. Avian influenza, egg prices, and policies balancing biosecurity and animal welfare in poultry production. *Food Policy*, 134:102882, 2025.

E. G. Weyl and M. Fabinger. Pass-through as an economic tool: Principles of incidence under imperfect competition. *Journal of Political Economy*, 121(3):528–583, 2013.

O. Zamani, T. Bittmann, and D. L. Ortega. The effect of avian influenza outbreaks on retail price premiums in the united states poultry market. *Poultry Science*, 103(10):104102, 2024.