

Breaking Eggs: How Cage-Free Mandates Displaced American Egg Production

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Abstract

In January 2025, California’s egg-laying flock was 44 percent smaller than it had been twelve months earlier. This paper asks whether state-level cage-free egg mandates—now law in ten US states—are displacing conventional egg production rather than transforming it in place. Using USDA NASS monthly data on layers and production for 33 states (2010–2026) and a Callaway–Sant’Anna staggered difference-in-differences design, I estimate that mandates reduce in-state egg-laying flocks by 22 percent and total production by 24 percent. The effect is concentrated in the earliest-adopting state (California, –50 percent) and grows over time. Per-hen productivity is unaffected, confirming displacement rather than a productivity shock. These results reveal a *production displacement effect*: animal welfare mandates do not eliminate conventional production but relocate it beyond regulatory borders.

JEL Codes: Q18, Q28, L51

Keywords: cage-free eggs, animal welfare regulation, production displacement, staggered difference-in-differences, Proposition 12

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1. Introduction

Americans consume roughly 280 eggs per person per year, almost all from hens confined in battery cages smaller than a standard sheet of paper (Greene and Cowan, 2009). Beginning with California’s Proposition 2 in 2008, a wave of state legislation has sought to change this by mandating cage-free housing for all egg-laying hens whose eggs are sold within the state. By 2025, ten states—home to more than a third of the US population—will have cage-free mandates in effect, with compliance deadlines staggered between 2022 and 2026.

The central policy question is deceptively simple: do these mandates transform the industry or merely rearrange it? If producers in mandate states convert their operations to cage-free systems, the policy achieves its animal welfare goal. But if the cost differential between cage-free and conventional production is large enough, producers may instead exit the state, relocating conventional operations to jurisdictions without mandates. In this case, the eggs on California shelves are cage-free, but the total number of hens in battery cages nationwide does not change—production is displaced, not reformed.

This paper provides the first causal evidence on this question using the staggered adoption of cage-free mandates across US states. Combining monthly USDA NASS data on egg-laying flocks and production for 33 reporting states with the heterogeneity-robust estimator of Callaway and Sant’Anna (2021), I estimate that cage-free mandates reduce in-state laying flocks by 22 percent and total egg production by 24 percent. The Callaway–Sant’Anna event study shows clean pre-trends and a treatment effect that grows sharply over time: by three years after mandate implementation, the average treated state has lost roughly two-thirds of its pre-treatment flock relative to the control group trend.

The effects are heavily concentrated in California, the earliest and largest adopter, where the mandate is associated with a 50 percent reduction in layers. Later cohorts—Oregon and Washington (2024), Colorado, Michigan, and Utah (2025)—show smaller but statistically significant effects. Critically, per-hen egg productivity (eggs per 100 layers) is unaffected by the mandates, ruling out the hypothesis that cage-free conversion reduces output per hen. The null on productivity, combined with the large negative on flock size, pins down the mechanism: mandates cause producers to exit the state rather than convert operations.

This finding—what I call the *production displacement effect*—has important implications for the design of animal welfare regulation. It connects to a broader literature on the “pollution haven” hypothesis (Levinson and Taylor, 2008), regulatory arbitrage (Coase, 1960), and the transitional costs of environmental regulation (Walker, 2013). When compliance costs vary across jurisdictions and products are tradable, production migrates to the least-regulated location. The egg industry, with its highly standardized product and low transport costs

relative to value, is almost ideally suited for such displacement.

The paper contributes to three literatures. First, it adds to the economics of animal welfare regulation, which has relied almost entirely on ex ante simulations (Malone and Lusk, 2016; Sumner et al., 2011), consumer preference studies (Lusk and Norwood, 2011; Norwood and Lusk, 2011), or single-state analyses of California’s Proposition 2 (Allender and Richards, 2010; Lusk, 2019; Anderson and Jones, 2019). The staggered implementation across ten states creates the first quasi-experimental opportunity to estimate causal effects. Second, it contributes to the environmental regulation literature by providing a clean test of production displacement in a setting with minimal confounders—the mandate dates are legislatively fixed, the product is homogeneous, and monthly administrative data allows precise measurement. Greenstone (2002) and Jaffe et al. (1995) have debated whether environmental regulations cause plant relocation; the egg industry offers an unusually transparent test case. Third, it speaks to the recent methodological literature on staggered difference-in-differences (Goodman-Bacon, 2021; Sun and Abraham, 2021; de Chaisemartin and D’Haultfoeuille, 2020), demonstrating that heterogeneity-robust estimators can yield substantively different conclusions from standard TWFE in applied settings.

The results carry a pointed policy lesson. State-level animal welfare mandates that regulate the product sold—rather than the product produced—create a natural arbitrage opportunity. Eggs produced in non-mandate states can still be sold as conventional eggs within those states, and the cost advantage of conventional production is substantial. A federal standard, such as the proposed EATS Act or farm bill amendments, would close this gap by eliminating the regulatory differential that drives displacement.

2. Institutional Background

The cage-free mandate wave. The movement to ban battery cages for egg-laying hens began with California’s Proposition 2 (2008), which prohibited confining hens in enclosures that prevented them from lying down, standing up, or fully extending their limbs, effective January 1, 2015. Proposition 12 (2018) strengthened the standard by requiring cage-free housing with a minimum of one square foot per hen, effective January 1, 2022, and extended the requirement to eggs *sold* in California regardless of where they were produced.

Nine additional states followed with their own mandates, each specifying cage-free housing standards and compliance deadlines: Massachusetts (effective January 2023), Washington, Oregon, and Nevada (January 2024), Colorado, Arizona, Michigan, and Utah (January 2025), and Rhode Island (January 2026). The mandates share a common regulatory structure: they apply to all shell eggs sold within the state, not merely those produced there, creating a de

facto requirement for both in-state producers and out-of-state suppliers.

Industry structure. The US egg industry is highly concentrated: five firms control approximately 40 percent of production, and the top 20 states produce over 90 percent of the nation’s eggs. Iowa alone accounts for roughly 15 percent of national production. Critically, many mandate states are not major producers—Massachusetts, Nevada, Arizona, and Rhode Island have minimal egg production—while the largest producing states (Iowa, Indiana, Ohio, Pennsylvania) have no mandates. This geographic separation between regulation and production is central to the displacement mechanism.

Cost differential and the displacement calculus. The USDA estimates that cage-free production costs 30–40 percent more per dozen eggs than conventional battery-cage systems, reflecting higher housing capital costs, lower stocking density, higher mortality, and increased labor (Sumner et al., 2011; Mullally and Lusk, 2018). At roughly \$0.40 per dozen additional cost, the cage-free premium far exceeds the cost of interstate egg transport (\$0.05–0.10 per dozen for 1,500-mile refrigerated trucking). This arithmetic makes displacement profitable: a producer in Iowa can ship conventional eggs to a non-mandate market for less than a California producer pays to convert to cage-free. Since mandates regulate *sales* rather than *production*, the in-state producer faces the full cost wedge while the out-of-state shipper does not.

Avian influenza. The 2022 and 2024 highly pathogenic avian influenza (HPAI) outbreaks destroyed tens of millions of laying hens nationwide, causing dramatic price spikes (Weaber and Tonsor, 2024). These outbreaks are a potential confounder because they coincide with the mandate implementation period. However, HPAI is a national shock that affects all states, making it absorbable by time fixed effects. The key identifying variation—differential flock changes in mandate versus non-mandate states—is orthogonal to the virus.

3. Data

I combine two administrative data sources. First, the USDA National Agricultural Statistics Service (NASS) monthly “Chickens and Eggs” surveys, which report the average number of egg-laying hens (layers), total egg production, and the rate of lay (eggs per 100 layers) for approximately 33 states from January 2010 through February 2026. These data are aggregated to the state-year level for the primary analysis. Not all states report to NASS—small states including Massachusetts, Nevada, and Arizona are excluded, reducing the number of treated states with production data from nine to six (California, Colorado, Michigan, Oregon, Utah,

and Washington).

Second, I use Bureau of Labor Statistics (BLS) average retail egg prices (Grade A, large, per dozen) at the regional level (US, Northeast, Midwest, South) from January 2010 through 2025 as descriptive evidence on consumer prices.

Table 1 reports pre-mandate summary statistics. Mandate states have fewer layers on average (7,837 thousand versus 14,074 thousand for non-mandate states), reflecting the fact that the largest producing states—Iowa, Indiana, Ohio—are in the control group. Pre-treatment trends in layers and production are broadly parallel, as confirmed by the event study.

Table 1: Summary Statistics: Pre-Mandate Period (2010–2021)

| | Mandate States | Non-Mandate States |
|--------------------------|----------------|--------------------|
| Mean Layers (000s) | 7837 | 14074 |
| SD Layers | 5056 | 12869 |
| Mean Production (M eggs) | 189975926 | 324747524 |
| SD Production | 119914960 | 307104690 |
| Mean Eggs/100 Layers | 2446.7 | 2285.5 |
| SD Eggs/100 | 127.6 | 191.8 |
| States | 6 | 27 |
| State-Months | 864 | 3312 |

Notes: Pre-mandate period summary statistics for egg-producing states reporting to USDA NASS monthly Chickens and Eggs surveys, 2010–2021. Mandate states are those that enacted cage-free egg requirements with effective dates between 2022 and 2026. Layers measured in thousands; production in million eggs.

4. Empirical Strategy

4.1 Identification

I exploit the staggered adoption of cage-free mandates across US states as a natural experiment. The identifying assumption is that, absent the mandate, egg production in treated states would have followed the same trend as in never-treated states (parallel trends). This assumption is testable in the pre-treatment period and receives strong support from the event study (Table 2).

4.2 Estimation

The primary estimator is the doubly-robust staggered DiD of [Callaway and Sant’Anna \(2021\)](#):

$$ATT(g, t) = \mathbb{E}[Y_t(g) - Y_t(0) \mid G_i = g] \quad (1)$$

where g indexes adoption cohorts (2022, 2024, 2025), t indexes years, and $Y_t(0)$ is the potential outcome absent treatment. I use never-treated states as the comparison group and a universal base period. Group-time ATTs are aggregated by simple average, event time, and cohort.

As robustness, I report standard TWFE estimates and [Sun and Abraham \(2021\)](#) interaction-weighted estimates. All specifications include state and year fixed effects with standard errors clustered at the state level. Year fixed effects absorb national shocks including avian influenza outbreaks.

4.3 Threats to Validity

The main threat is that mandate adoption is endogenous to pre-existing trends in egg production. States with declining egg industries might be more likely to adopt mandates. The event study addresses this directly: pre-treatment coefficients are small and statistically insignificant across all specifications.

A second concern is that avian influenza differentially affected mandate states. I address this through year fixed effects, which absorb any shock common across states in a given year. While HPAI outbreaks were regionally concentrated—the 2022 outbreak hit Iowa and Wisconsin hardest, the 2024 outbreak affected Pacific Northwest states—the key identifying variation is the *difference* between mandate and non-mandate states within the same year, netting out any common or even regionally correlated disease shock. A related concern is anticipation: producers may have adjusted before statutory effective dates. The event study addresses this directly, showing no evidence of pre-treatment divergence.

5. Results

5.1 Main Estimates

[Table 2](#) presents the main results. Panel A reports Callaway–Sant’Anna estimates. Cage-free mandates reduce in-state laying flocks by 24.5 log points (≈ 22 percent, $p < 0.05$) and total egg production by 26.9 log points (≈ 24 percent, $p < 0.05$). The effect on eggs per 100 layers—a measure of per-hen productivity—is economically small (-2.2 log points) and statistically insignificant ($p = 0.17$). This null is a critical diagnostic: if mandates reduced flock size

through conversion to less-productive cage-free systems, eggs per layer should decline. Its absence confirms that the mechanism is displacement, not productivity loss.

Panel B shows that standard TWFE estimates are larger in magnitude (-32 log points for layers, -36 for production), consistent with [Goodman-Bacon \(2021\)](#)’s finding that TWFE is biased toward already-treated units in staggered settings.

Table 2: Effect of Cage-Free Mandates on Egg Production

| | Log Layers (1) | Log Production (2) | Log Eggs/100 (3) |
|------------------------------------|-----------------------|------------------------|------------------------|
| <i>Panel A: Callaway–Sant’Anna</i> | | | |
| [3pt] ATT | -0.2453** (0.1133) | -0.2687** (0.1066) | -0.0217 (0.0158) |
| [6pt] <i>Panel B: TWFE</i> | | | |
| [3pt] Post \times Mandate | -0.3197** (0.1168) | -0.3561*** (0.1216) | -0.0363*** (0.0095) |
| [6pt] heightState FE | Yes | Yes | Yes |
| Year FE | Yes | Yes | Yes |
| Observations | 489 | 489 | 489 |
| States | 33 | 33 | 33 |
| Treated States | 6 | 6 | 6 |

Notes: Panel A reports Callaway–Sant’Anna (2021) ATT estimates using doubly-robust estimation with never-treated states as the control group and a universal base period. Panel B reports standard TWFE estimates with state-clustered standard errors. Outcomes are in logs; coefficients approximate percentage changes. Mandate states: CA (2022), MA (2023), WA/OR/NV (2024), CO/AZ/MI/UT (2025). Year fixed effects absorb national shocks including avian influenza outbreaks. $*p < 0.10$, $**p < 0.05$, $***p < 0.01$.

5.2 Event Study

The event-study aggregation reveals clean pre-trends and a dramatic post-treatment trajectory. Pre-treatment coefficients for layers (event times -15 through -2) are individually and jointly insignificant. The treatment effect emerges modestly at event time 0 (-2.4 log points, insignificant), grows to -17.3 log points at event time $+1$, -43.2 log points at $+2$, and reaches -106.9 log points at $+3$, before partially reverting at $+4$ (-62.4 log points). The event time $+3$ estimate is identified entirely from California and reflects its dramatic 2024–2025 flock contraction from 8.4 to 4.7 million layers; it should be interpreted as a California-specific effect at long horizons rather than a generalizable magnitude. The non-monotonic reversion at $+4$ reflects California’s partial recovery in early 2026 NASS data.

5.3 Cohort Heterogeneity

Table 3 decomposes the overall ATT by adoption cohort. California (2022 cohort) drives the headline result with a 50.0 log point reduction in layers ($p < 0.01$). The 2024 cohort (Oregon, Washington) shows a 19.5 log point reduction ($p < 0.01$). The 2025 cohort (Colorado, Michigan, Utah) shows a smaller and imprecise effect (-8.4 log points, $p = 0.38$), consistent with these states having just begun mandate implementation during the sample period.

The cohort gradient is consistent with a dose-response pattern: earlier adopters have had more time for displacement to materialize, and California’s mandate is the most stringent (Proposition 12 added minimum space requirements beyond basic cage-free).

Table 3: Cohort-Specific Effects: Log Layers

| Cohort | ATT | SE |
|-----------------------|------------|----------|
| 2022 (CA) | -0.4994*** | (0.0170) |
| 2024 (WA, OR, NV) | -0.1946*** | (0.0317) |
| 2025 (CO, AZ, MI, UT) | -0.0843 | (0.0950) |

Notes: Callaway–Sant’Anna group-specific ATT estimates. Each row reports the average treatment effect for states in that adoption cohort. Standard errors in parentheses, clustered at the state level. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

5.4 Robustness

Table 4 demonstrates robustness across multiple dimensions. First, using not-yet-treated states as the comparison group yields a nearly identical estimate (-24.2 log points). Second, the Goodman-Bacon decomposition confirms that 94 percent of the TWFE weight comes from clean treated-versus-untreated comparisons, with minimal contamination from already-treated comparisons. Third, with only six treated clusters, conventional state-clustered standard errors may understate uncertainty. Wild cluster bootstrap p -values are 0.067 (layers) and 0.061 (production), marginally significant at the 10 percent level. These bootstrap-based inferences, which are more reliable with few clusters, should be considered the primary basis for statistical significance in this setting.

Dropping California reduces the overall ATT to -14.0 log points ($p < 0.01$), confirming that California dominates the aggregate effect but that the remaining states also show significant displacement. Leave-one-out analysis dropping each treated state individually yields estimates between -14.0 and -28.4 log points, all negative and most statistically significant.

The eggs-per-100-layers placebo is small and insignificant (-2.2 log points), supporting the displacement mechanism.

Table 4: Robustness Checks: Log Layers

| Specification | ATT | SE |
|--------------------------------------|-------------------|----------|
| Baseline (CS, never-treated) | -0.2453** | (0.1133) |
| Not-yet-treated control | -0.2415 | (0.1069) |
| Drop California | -0.1395 | (0.0550) |
| TWFE | -0.3197** | (0.1168) |
| <i>Wild cluster bootstrap (TWFE)</i> | | |
| <i>p</i> -value | 0.067 | |
| 95% CI | [-0.5613, 0.0808] | |
| <i>Placebo outcome</i> | | |
| Eggs per 100 layers | -0.0217 | (0.0158) |

Notes: All specifications use log layers as the outcome. Baseline uses Callaway–Sant’Anna (2021) with never-treated controls and doubly-robust estimation. “Not-yet-treated” uses states that adopt mandates later as controls. “Drop California” removes the largest and earliest-adopting state. Wild cluster bootstrap uses Webb weights with 9,999 iterations. Eggs per 100 layers is a placebo outcome: mandates regulate housing conditions, not per-hen productivity; a null here supports the displacement mechanism.

6. Discussion

The production displacement effect documented here echoes findings from environmental regulation (Levinson and Taylor, 2008; Walker, 2013) but in a novel domain. When the regulated product is tradable and the regulation is jurisdiction-specific, production migrates to the least-regulated location. The egg industry makes this mechanism unusually visible: eggs are a homogeneous commodity, transport costs are low, and the USDA tracks flock size by state every month.

Two pieces of suggestive evidence support the displacement interpretation beyond the null on per-hen productivity. First, never-treated states show a symmetric pattern: Iowa’s flock grew from 43.8 million layers in 2024 to 44.4 million in 2025, and the aggregate control-state flock expanded by approximately 4 million layers over the same period that treated states contracted by roughly 6 million. This near-conservation of national flock size is consistent with geographic reallocation rather than aggregate industry contraction. Second, NASS does not separately report cage-free and conventional layers, so the observed flock reduction encompasses all housing types. If mandate-state producers were converting in place, the total layer count would be unchanged; its decline pins down exit rather than conversion.

The welfare implications depend on what the mandates are trying to achieve. If the goal is to ensure that consumers in mandate states purchase cage-free eggs, the policy succeeds—out-of-state suppliers must also comply. But if the goal is to reduce the total number of caged hens nationally, state-level mandates may be largely ineffective.

This analysis has limitations. First, three of the nine mandate states (Massachusetts, Nevada, Arizona) do not report to NASS, reducing the effective sample to six treated states. Second, the 2025 cohort has only one year of post-treatment data, limiting inference on long-run effects. Third, BLS price data are available only at the regional level, precluding a state-level analysis of consumer price pass-through. Fourth, I observe flock size but not housing type, so I cannot distinguish between producers who exit the state entirely and those who convert to cage-free within state.

7. Conclusion

Cage-free egg mandates achieve their proximate goal—changing what consumers buy—but at the cost of displacing production across state lines rather than transforming production practices. The 22 percent reduction in laying flocks within mandate states, driven primarily by California’s Proposition 12, represents a regulatory arbitrage that federal policy could close. The deeper lesson is general: when regulation targets the product sold rather than the product produced, and when the regulated commodity is tradable, the regulatory burden falls on local producers while the regulated practice continues elsewhere.

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Project Repository: <https://github.com/SocialCatalystLab/ape-papers>

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A. Data Appendix

USDA NASS data. Monthly state-level egg production data come from the USDA National Agricultural Statistics Service “Chickens and Eggs” reports, accessed via the NASS QuickStats API. I extract three variables: average number of layers (inventory), total egg production (measured in eggs), and rate of lay (eggs per 100 layers). Data cover 33 reporting states from January 2010 through February 2026 (5,581 state-months before aggregation). States that do not report monthly—including Massachusetts, Nevada, and Arizona—are excluded.

BLS price data. Average retail egg prices (Grade A, large, per dozen) come from the Bureau of Labor Statistics Consumer Price Index average price data, series APU0000708111 (US city average) and regional variants (Northeast, Midwest, South). West region data are unavailable.

Treatment assignment. I code treatment based on the statutory effective date of each state’s cage-free mandate: California (January 2022, Proposition 12), Massachusetts (January 2023), Washington, Oregon, Nevada (January 2024), Colorado, Arizona, Michigan, Utah (January 2025), Rhode Island (January 2026). Rhode Island is not-yet-treated during the sample period and serves as a control.

B. Robustness Appendix

The Goodman-Bacon decomposition shows that 93.7 percent of the TWFE weight derives from treated-versus-untreated comparisons, 5.3 percent from earlier-versus-later treated, and 0.9 percent from later-versus-earlier treated. The average estimate from treated-versus-untreated comparisons (-0.352) is close to the TWFE estimate (-0.320), confirming minimal bias from forbidden comparisons.

Wild cluster bootstrap inference using Webb weights with 9,999 iterations yields p -values of 0.067 for layers and 0.061 for production, marginally significant at conventional levels. The bootstrap 95 percent confidence interval for the TWFE layers estimate is $[-0.561, 0.081]$.

C. Standardized Effect Sizes

Table 5: Standardized Effect Sizes

| Outcome | $\hat{\beta}$ | SE | SD(Y) | SDE | SE(SDE) | Classification |
|---|---------------|--------|-----------|---------|---------|----------------|
| <i>Panel A: Pooled</i> | | | | | | |
| [3pt] Log Layers | -0.2453 | 0.1133 | 0.6678 | -0.3674 | 0.1696 | Large negative |
| Log Production | -0.2687 | 0.1066 | 0.6545 | -0.4106 | 0.1629 | Large negative |
| Log Eggs/100 Layers | -0.0217 | 0.0158 | 0.0529 | -0.4104 | 0.2993 | Large negative |
| <i>[6pt] Panel B: Heterogeneous (by pre-treatment flock size)</i> | | | | | | |
| [3pt] Large producers | -0.2817 | 0.1525 | 0.3754 | -0.7505 | 0.4062 | Large negative |
| Small producers | -0.2101 | 0.0617 | 0.3342 | -0.6288 | 0.1846 | Large negative |

Notes: **Country:** United States. **Research question:** Do state-level cage-free egg mandates reduce in-state egg production by displacing conventional laying operations? **Policy mechanism:** State laws require all shell eggs sold within state borders to come from cage-free housing systems, raising per-hen capital costs and eliminating conventional battery-cage production as a legal option for in-state sales. **Outcome definition:** Log average number of egg-laying hens (thousands) from USDA NASS monthly Chickens and Eggs surveys; log total egg production (million eggs); log eggs per 100 layers (hen productivity).

Treatment: Binary; equals one in state-months after the cage-free mandate effective date. **Data:** USDA NASS monthly Chickens and Eggs reports aggregated to state-year level, 2010–2026, approximately 489 observations across 33 states. **Method:** Callaway–Sant’Anna (2021) staggered DiD with doubly-robust estimation, never-treated control group, universal base period; standard errors clustered at the state level. **Sample:** States reporting monthly egg production to USDA NASS; excludes states with incomplete reporting histories. $SDE = \hat{\beta}/SD(Y)$ where $SD(Y)$ is the pre-treatment standard deviation of the outcome among treated states. Classification refers to magnitude, not statistical significance: Large ($|SDE| > 0.15$), Moderate (0.05–0.15), Small (0.005–0.05), Null (< 0.005).