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IMPACT OF CORPORATE COMMITMENTS TO SOURCE CAGE-FREE EGGS ON LAYER HEN HOUSING


Preregistration for an observational study

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EXECUTIVE SUMMARY Over the last decade, hundreds of companies around the world have committed to source cage-free eggs by 2025 or earlier. Commitments sometimes result from conversation with groups advocating to improve the treatment of animals, as cage-free housing is widely believed to provide better welfare for egg-laying hens. When conversation does not work, advocacy groups may run a campaign of public pressure, including protests or shaming in the media, which usually leads to a commitment. In this preregistration, we describe a detailed plan to use data from many countries on the share of hens living cage-free to understand the effect of cage-free commitments. We expect that commitments will shift the industry from caged to cage-free housing for hens. To test this, we will look at data from before and after commitments were made and in countries with and without commitments. We will also consider other factors, like changes in the law and illnesses that kill hens, that could affect how they are housed. We suspect that commitments and housing affect each other, so we will use advocacy groups' campaigns as a statistical tool to further clarify the cause-and-effect relationship. When we complete the planned study, it will provide thorough evidence on the impact of cage-free commitments, which might be useful to advocacy groups, companies making commitments, and the egg industry.

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All current and future files related to this project will be available in the associated Open Science Framework repository at <https://osf.io/VTE94/>.



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1. INTRODUCTION

Egg-laying hens housed in battery cages are intensively confined, living in less than half a square foot of space [1], and suffer from numerous welfare issues [2]. Cage-free housing for layer hens provides improved welfare, allowing hens space to move more freely and express natural behaviors. Consumers also value animal welfare [3; 4; 5]. However, this does not always manifest in consumer behavior, likely in part because consumers have incomplete information about animal welfare when making purchasing choices [6]. Thus the suffering of farm animals represents losses of both animal welfare and consumer welfare.

Starting in 2005, many corporations made commitments to source cage-free eggs, often with deadlines to complete the sourcing several years in the future. As of 2019, nearly

400 retailers, restaurants, and food service companies with operations in the United States (US) have made commitments [7], and cage-free commitments have also spread globally. Commitments are sometimes facilitated by dialogue with animal advocacy groups, like The Humane Society of the United States, The Humane League¹, and Mercy for Animals. In other cases, the commitments followed public campaigns by animal advocacy groups employing pressure tactics, including on-the-ground protests, newspaper ads, petitions, shareholder activism, and undercover investigations. In either case, these commitments can be interpreted as correcting the market failures associated with the externalization of poor animal welfare and the incomplete information facing consumers.

This preregistration provides a detailed plan to evaluate the impact of corporate commitments to source cage-free eggs in actually changing layer hen housing. All current and future files for this project will be located in the associated Open Science Framework repository at <https://osf.io/vte94/>. Using an observational design, we will analyze a newly constructed longitudinal data set tracking hen housing conditions from a group of countries on an annual basis. The data set will include countries with many commitments and very few or no commitments, as well as baseline data from before commitments were made in some countries. Instrumental variables estimation and models for longitudinal data will be used to estimate a causal effect, with public pressure campaigns as an instrument.

As a confirmatory study, we plan to test the hypothesis that corporate cage-free commitments increase the percentage of layer hens living in cage-free housing systems in a country's egg industry. Our initial observations of the US egg industry support this hypothesis: as the cumulative number of commitments has increased, so too has the percentage of cage-free hens, from 3.2% in 2007 to 20.4% in July 2019 (Figure 1; [8]). The steady increase in cage-free hen housing likely reflects the capital-intensive and therefore slow nature of the infrastructure changes needed to shift production methods, which is also reflected in the multi-year timelines for most cage-free commitments. In the US, several large committed corporations (for example, Costco, Compass Group, and Sodexo) have published updates on their progress toward sourcing exclusively cage-free eggs, which suggests that committed companies are

¹ See Section 6.2 “Conflicts of interest” for more information on the relationship between The Humane League Labs and The Humane League.

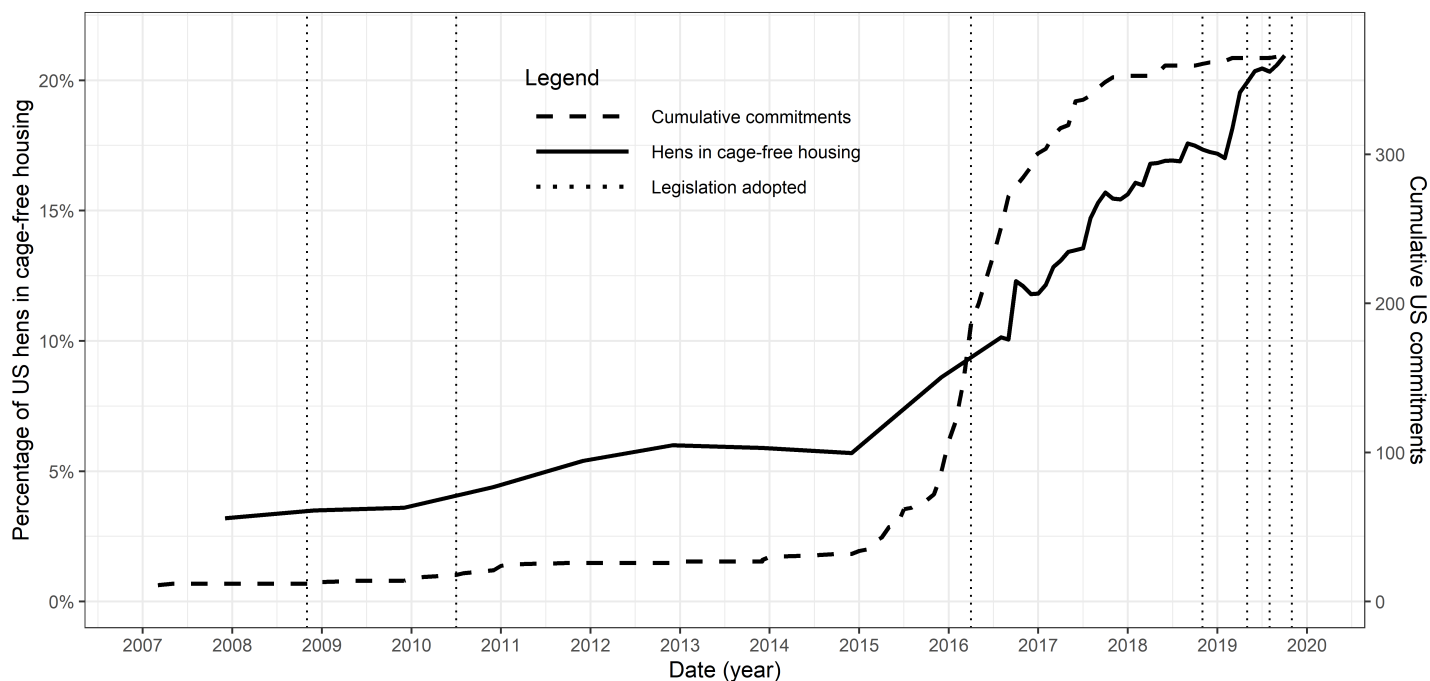


Figure 1 The cumulative number of corporate commitments in the US [7] versus the percentage of US hens in cage-free housing [8] from 2007 to 2019. The two are closely correlated, with an increase in cage-free housing associated with the increase of commitments, preceded by years of only modest increases in cage-free housing. For reference, the dates of enactment (rather than enforcement) of state-level cage-free laws are indicated with dotted vertical lines (see Section 2.4). Data are available at <https://osf.io/vte94/>.

increasing their demand for cage-free eggs and, it is hypothesized, causing the increase in production [9; 10]. Animal advocates and industry analysts also publicly express support for this hypothesis [11; 12], as do previous studies of the US cage-free commitments (see Section 1.1). However, we will improve on the existing literature by directly attempting to identifying causation, examining commitments globally, and explicitly including legislation² and avian influenza outbreaks as additional explanatory variables. By obtaining geographically and temporally expansive empirical evidence and including relevant explanatory variables, this study will attempt to rigorously estimate the effect of corporate cage-free commitments. Furthermore, we will explore the impact of legislation, which is also expected to increase the percentage of cage-free housing. The results of this research will then be useful to advocacy groups, the egg industry, and businesses considering adopting policies to improve animal welfare or other socially responsible policies.

² Here we use *legislation* to refer to any law affecting hen housing, rather than the legal sense of a law passed specifically by a legislative body.

1.1. Literature overview

Several studies have previously examined the role of corporate commitments in increasing the percentage of hens in cage-free housing, as well as improving the welfare of chickens raised for meat, termed *broiler chickens*. Most directly relevant to our work is Sarek’s [13] quantitative model of US cage-free egg production, which attributes an increase of between 2.1 and 10 percentage points of cage-free egg production from 2005 to 2018 to corporate commitments. The analysis uses consumer willingness-to-pay and demand; retail prices and price premium between caged and cage-free eggs; avian influenza rates; and historical trends to estimate the counterfactual percentage of cage-free housing. As the author acknowledges, data limitations restrict the explanatory power of the estimates. Šimčíkas [14] examines the cost-effectiveness of advocacy to obtain corporate commitments in improving animal welfare, including both layer hens and broiler chickens. The calculation of the number of chickens affected by commitments includes a descriptive analysis of the counterfactual scenario without intervention by animal advocates. The study estimates between 9 and 120

years of chicken life (combing laying hens and broiler chickens) are improved per dollar spent by advocacy groups to obtain corporate commitments. Capirati [15] uses a case series to examine the role of animal advocacy in obtaining corporate commitments, including two cage-free and two broiler commitments, and estimates the cost-effectiveness of these efforts. The report positively links animal advocacy efforts to corporate commitments and estimates 10 years of layer hen life are affected per dollar spent [15, p58]. Collectively, these studies all suggest that corporate commitments, and advocacy efforts to obtain those commitments, caused increases in the percentage of cage-free housing. In addition, Šimčíkas and Capirati suggest corporate commitments have caused improvements in the welfare of broiler chickens. However, these studies are limited by a lack of rigorous strategies for identifying causation, a focus on the US, and the exclusion of the potential effects of legislation (though Šimčíkas qualitatively discusses how legislation could affect cost-effectiveness estimates).

Two additional studies examine the broiler welfare corporate commitments. Saatkamp et al. [16] examine factors that contributed to the Dutch broiler chicken industry's transition to higher welfare standards. Using expert elicitation, they find "initiating and triggering actions by non-governmental organizations" [16, p1] and a willingness on the part of the entire value chain to change as two of five main factors. Furthermore, a "rapid and complete change" [16, p2] in the industry toward higher welfare standards is attributed to a 2012 decision by several large retailers to discontinue carrying conventional broiler chicken meat in their stores. Reis and Molento [17] use content analysis of the annual reports of two major broiler producers and five semi-structured interviews to conclude that the European adoption of broiler chicken welfare standards may improve animal welfare. While these studies share limitations with the previously cited studies, the findings again support the role of corporate commitments in improving animal welfare and advocacy campaigns in achieving those commitments.

Campaigns by advocacy groups and the resulting corporate commitments have also been suggested to cause reductions in the number of rabbits harmed in cosmetics testing, animals killed for fur production, and dolphins harmed as bycatch in the tuna industry. Henry Spira and his group Animal Rights International ran numerous campaigns against the testing of cosmetics on animals and popularized the strategy in animal advocacy [11]. In a book-

length case series, Singer partially attributes reductions in the number of animals harmed in cosmetics testing in the later 1970s [18, p113] and the eventual abandonment of animal testing by many large cosmetics companies in 1989 [18, p135] to these campaigns and commitments. In a case study of the global fur industry, Bollard [19] attributes some of the recent decline in the number of animals killed for fur to targeted campaigns that obtained 1,017 fur-free corporate commitments. Lastly, in a case study of the tuna industry, Mitchell [20] found corporate pledges to source dolphin-safe tuna were caused by consumer boycotts and environmental advocacy. These pledges may have then led to US and international government regulation, which ultimately succeeded in reducing the number of dolphins harmed through tuna fishing. These studies suggest a more general effect of corporate commitments, and campaigns by advocacy groups to obtain those commitments, for improving animal welfare across a variety of animal industries and theories of change.

Our study will also inform the broader literature on corporate social responsibility and market-driven governance, where a thread of research focuses on the effectiveness of corporate commitments, pledges, and voluntary labeling in causing change in the supply chain. Empirical research on the impact of corporate initiatives and commitments to limit deforestation shows mixed results, ranging from small reductions in deforestation [21; 22] to no statistically significant effect [23; 24]. The empirical literature on the effect of voluntary supplier codes-of-conduct on workers' rights generally finds a small but statistically significant effect [25], and the effect size tends to increase with improvements to study methodology such as more comparable control groups and finer-grained data [26; 27]. These results suggest positive effects of corporate commitments in non-animal industries as well. This study will extend the literature to consider the impact of corporate social responsibility as it pertains to animal welfare.

1.2. Outline

This preregistration proceeds as follows. In Section 2, we describe the egg industry and the historical setting of our study. Section 3 provides an analysis plan describing the data sources and collection strategies; the empirical approach; estimation procedures; and potential residual risks of bias. Section 4 concludes with a discussion of other potential limitations, anticipated results, and possible future extensions.

2. BACKGROUND

To understand the most important features determining layer hen housing, we provide institutional context about the modern egg industry and historical context around the study period. We focus on the aspects of egg production that inform how egg producers choose their flock sizes and housing systems year after year and confine the historical narrative to broad examples of how commitments, legislation, and the avian influenza outbreak affected the egg industry.

Egg production consists of multiple stages; the most recognizable stage is *laying*, in which *table-egg-laying hens* produce eggs intended for human consumption. Further upstream, *hatching-egg-laying hens* produce eggs to replenish the table-egg-laying flocks.³ Downstream, egg processors clean, grade, sort, process, and pack the eggs for retailers and restaurants. As with many other agricultural supply chains, the egg industry is highly integrated, so that the egg producer often owns the hatchery, laying barns, and processing facilities [28]. This integration minimizes transaction costs, reduces the number of decision-makers, and gives producers control over production capabilities [28].

2.1. Productive cycles and short-run production variables

Egg producers raise egg-laying hens in flocks, groups of chickens of approximately the same age. Once a flock of young chickens, *pullets*, enters the egg-laying barn, the egg producer can add new pullets to incomplete flocks for up to three weeks [1]. These hens will remain together in the same barn for the length of the laying cycle, which depends on breed, season, consumer preferences, feed costs, and egg prices [29]. The laying cycle is typically 60 to 72 weeks but may be extended to 109 weeks through *molting* [29; 30; 31], which can be harmful to hen welfare [32]. After a molting period, hens return to producing larger, higher-quality eggs at a faster rate in another, potentially shorter, laying cycle [31]. Producers can use variation in the length of cycles, molting, timing of flock replacement, and reductions of stocking density to respond to short-term changes in market conditions [29; 33; 34].

³ For brevity, we use *egg-laying hens* to refer just to *table-egg-laying hens* hereafter.

2.2. Housing types and long-run production variables

Egg producers rarely under-utilize space in existing hen housing facilities, so the decision to increase cage-free flocks requires either building new housing structures or converting existing structures. Housing systems have different physical structures and different implications for flock management and animal welfare, so a high-level overview of the features of these systems provides context for understanding the producers' investment decisions as well as the advocacy and legislative history discussed below. The most relevant housing systems for this study are battery cage and cage-free housing; however, we briefly examine features of several other relevant housing systems.

Most egg-laying hens are currently housed in *battery cages* (also called *non-enriched* or *barren* cages), which are stacked in rows, and are themselves inside a barn. These cages provide very little space per hen and provide no way for hens to express natural behaviors [1]. *Enriched cages*, commonly used in EU countries, have more space per hen and contain enrichments like nests, perching space, litter, and feed troughs within the cages to allow hens to express natural behaviors [35]. Enriched cages are seen as an intermediate welfare improvement between battery cages and cage-free housing [36]. Cage-free housing includes a variety of systems without cages in which birds have the ability to express natural behaviors. Specifically, hens must be able to move in a way that promotes their welfare, be protected from predators, and have access to litter. Hens are provided enrichments such as perches, nests, and scratching areas to allow them to perform natural behaviors [37]. *Aviary* and *barn* systems are two examples of cage-free housing. Birds freely roam inside the buildings in both systems; however, in barn systems, birds generally live on one level, while aviary systems have multiple levels for perching [38]. Other systems may exceed the housing space requirements of cage-free systems. Although the USDA does not currently define or grade eggs marketed as *pasture-raised*, both pasture-raised flocks as defined by third-party certifiers⁴ and USDA-certified *free-range* flocks have housing requirements that encompass and exceed the requirements of cage-free systems [37; 39; 40].

The transition from battery cages to cage-free housing in the US is estimated by industry analysts to cost between \$30 and \$40 per bird (including both long-term capital costs as well as variable operation costs) and require several years to

⁴ Examples include American Humane and Certified Humane.

complete [41]. From an empirical modeling perspective, we expect that the changes in percentage of hens in cage-free housing are influenced less by short-term variables like previous flock size and more by long-term variables that enter the housing investment decision like long-run price trends, demands of downstream corporate customers (e.g., cage-free commitments), retail consumer demand, and legislation.

2.3. Animal advocacy and corporate commitments

In the early 2000s, US animal advocacy groups began to scale up corporate engagement tactics alongside investigative and legal strategies, with a focus on engaging consumer-facing food businesses rather than egg producers [11]. The first comprehensive national commitments to source all egg products exclusively from cage-free hens were made in 2005 by retailers Whole Foods, Wild Oats, and Earth Fare. Other early commitments to source cage-free eggs were either made by niche retailers and restaurants or covered only part of a company's egg usage. For example, major institutional food service companies Sodexo and Aramark committed to sourcing cage-free shell eggs in 2012 and 2013 respectively but did not include liquid eggs in their stated commitments [42; 43]. In response to initial success, advocacy groups invested more time in corporate dialogue and pressure campaigns. In early 2015, Sodexo and Aramark updated their commitments to cover all egg products by 2020, and their competitor Compass Group North America released a commitment to cover all egg products in their US operations by 2019. Soon after, other companies began to make commitments in quick succession. The majority of cage-free commitments were made between 2015 and 2017, the period during which most campaigns were conducted. Many companies who committed during this time, like McDonald's, Costco, Walmart, Kroger, Denny's, and Nestle, use a large quantity of the eggs sold in the US and thus affect a large number of hens.

The case of warehouse grocer Costco illustrates the connection between campaigns and commitments. In 2015, a coalition of advocacy groups began a pressure campaign against Costco to secure a cage-free commitment after failed attempts at dialogue. Pressure tactics included on-the-ground protests, newspaper ads, petitions, shareholder activism, and publication of undercover footage of poor welfare standards in Costco's supply chain. The corporation made a cage-free commitment in December 2015 and

now provides regular updates on its progress. The most recent update indicates that 89% of shell eggs sold in its US operations were cage-free as of September 2018, which impacts roughly 9.6 million hens each year [10; 44].

As most large US companies have now committed to sourcing cage-free eggs, the influx of cage-free commitments has moved from the US to other countries globally. Certain European countries like Belgium, Germany, and France gained commitments between 2005–2014, a few years earlier than the groundswell in the US. However, other countries like Italy, Latvia, and Poland are beginning to see a large number of new commitments, in 2016 and beyond. The expanded efforts of international advocacy groups like the Open Wing Alliance likely explain these recent commitments. To date, about 800 cage-free commitments affect European operations, and about 400 commitments affect countries outside of the US and EU [7]. These observations provide invaluable variation over time and space that can be used to better estimate the causal effect of commitments on the percentage of hens in cage-free housing.

2.4. Hen housing legislation

In 2008, California adopted a ballot initiative, Proposition 2, titled "Standards for Confining Farm Animals." Proposition 2 prohibited the confinement of certain farm animals in a manner that does not allow them to lie down, stand up, fully extend their limbs, and turn around freely [45]. While the adoption of the law represented a victory on the part of groups that campaigned for the law starting in 2005, the vague wording of the bill allowed for enriched cages, and some producers switched from conventional cages to enriched cages as a means of compliance with the new law [11]. In 2010, the California legislature passed AB 1437, requiring all eggs sold in California to meet the standards outlined in Proposition 2 by January 1, 2015 [46].

Following the lessons learned from Proposition 2 and AB 1437, initiatives in other states banned sales of *all* caged eggs, regardless of whether they were sourced outside the state or from enriched cages. In 2016, Massachusetts voters approved such a measure with 77% support, which will take effect in 2022 [47]. In California in 2018, Proposition 12 or the "Prevention of Cruelty to Farm Animals Act" improved on Proposition 2 to require at least 144 in² (929 cm²) of floor space in barns without cages by January 1, 2020 [48; 49]. Proposition 12 will ban cages for layer hens

after December 31, 2021. In 2019, legislatures in Michigan, Washington, and Oregon adopted cage-free laws, including sales bans, which come in to effect in December 2024, January 2024, and January 2024, respectively [50; 51; 52].

In the EU, 1999 legislation establishing minimum standards for egg-laying hens effectively banned the use of battery cages beginning in 2012 [53]. Germany, Austria, the Netherlands, and Sweden passed legislation of their own, with Germany and the Netherlands establishing stricter standards than the EU legislation [54]. Since the EU-wide legislation still allows for the use of enriched cages, advocacy groups have continued to work towards cage-free commitments for European food businesses. Outside of the EU, Switzerland banned all types of cages for egg-laying hens in 1992 [54; 55].

2.5. Highly pathogenic avian influenza

For six months starting in December 2014, a highly pathogenic avian influenza (AI) swept through US chicken and turkey flocks. Over 50 million birds died from contracting AI directly or were killed to quarantine the AI, representing 12% of the US egg-laying flock [56]. The sudden supply shock increased US egg prices to record highs and reduced exports; the stigma of the disease impacted both domestic and overseas consumer demand. Although observed outbreaks of the disease ended sharply in June 2015, the effects on the market and market prices were long-lasting. Egg prices in 2016 were even more volatile than usual, and the attempt to rebuild flocks after the depopulation caused imbalances in the usually seasonal supply of eggs [56]. As prices of conventional eggs increased and the price premium between cage-free and conventional eggs shrank, more consumers chose cage-free eggs in the grocery stores. Ramos [56] suggests that expanded demand for cage-free eggs alongside the need to replace flocks after the AI outbreak may have prompted egg producers to invest in cage-free housing and increase their cage-free flock sizes relative to conventional flocks. AI impacted Europe much less dramatically, and the birds affected were largely not egg-laying hens [57].

3. METHODS

Since hundreds of corporate commitments have already been made around the world, it is unlikely that experimental methods could be used to test the main hypothesis of this work. With observational data available, we will attempt to understand the effect of corporate commitments

on cage-free housing while accounting for potential sources of bias inherent to the research design. Here, we detail our planned methodology with a focus on explaining our modeling choices and the high-level advantages and disadvantages of the estimation procedures. References are provided for readers interested in understanding the estimation methods in greater detail.

We plan to compare three estimation procedures and models. The three procedures are variations of a general mixed effects model: a fixed effects (FE) model, a linear correlated random effects (CRE) model, and a nonlinear CRE model. To compare models, we'll use a modified Hausman test and a modified Akaike Information Criterion. We will specifically consider potential sources of bias, including unobserved consumer preferences and feedback loops in the commitment–cage-free housing relationship, and how different models may mitigate bias.

3.1. Empirical model

Figure 2 provides a conceptualization of the causal mechanisms investigated in this study. The main effect of interest is the causal pathway from corporate commitments (lower left) to the percentage of cage-free hen housing (lower right). The other elements represent variables that may influence the outcome variable, the main explanatory variable, or both. Directional arrows indicate the theorized direction of the causal relationship so that bi-directional arrows imply a feedback loop. The empirical model must account for observed and unobserved variables as well as correlations between variables. We exploit the longitudinal nature of the data to analyze the impacts of corporate commitments at the country level over time. Thus, we model the percentage of hens living in cage-free housing in country i and year t as the following relationship,

$$\begin{aligned} \text{perc_hens_cage_free}_{it} = & \beta_0 \\ & + \beta_1 \text{cumulative_commitments}_{it} \\ & + \beta_2 \text{legislation}_{it} + \beta_3 \text{flu}_{it} + \beta_4 t \\ & + v_i + u_{it} \end{aligned}$$

where

- $\text{perc_hens_cage_free}_{it}$ is the percentage of all commercial egg-laying hens in country i and year t living in cage-free housing;
- $\beta_0 \dots \beta_4$ are coefficients to be fit during the estimation;

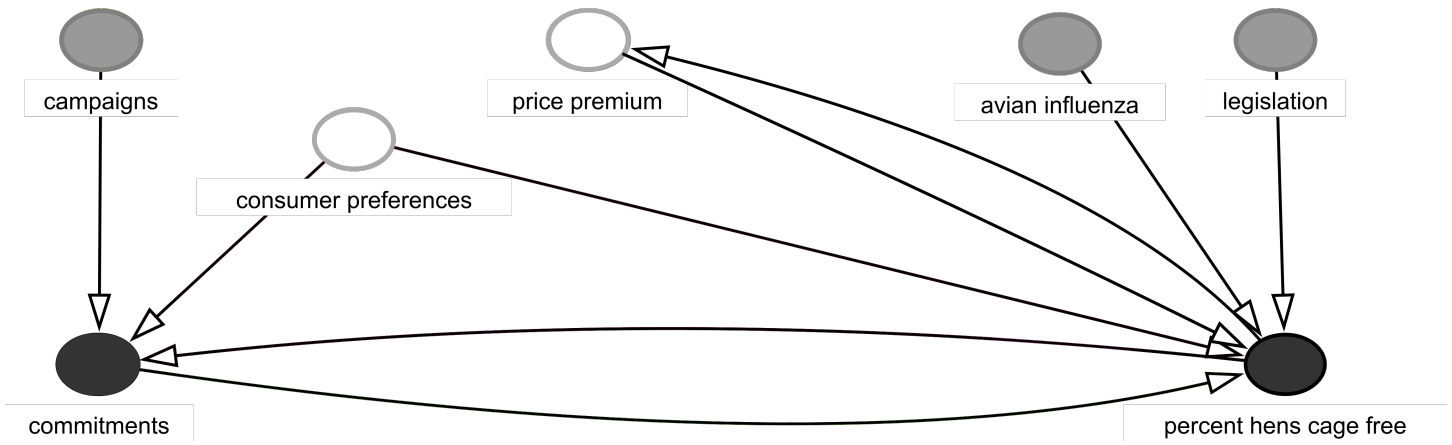


Figure 2 A directed acyclic graph (DAG) of the theorized causal mechanisms. White circles indicate unobserved variables, grey circles observed variables, and black circles the explanatory variable of interest and the outcome.

- $cumulative_commitments_{it}$ is the cumulative number of corporate cage-free commitments in country i and year t ;
- $legislation_{it}$ is an indicator variable that equals one in year t if country i has enacted legislation banning either battery or all cages in year t or any previous year;
- flu_{it} is the cumulative number of chickens killed by avian influenza outbreaks in country i and year t ;
- t is the annual time trend;
- v_i are the unobserved effects in country i ; and
- u_{it} is the country-year error term for country i and year t .

Due to data availability as well as the inherent difficulties in identifying price effects in estimations of supply and demand, we omit price from our analysis. The most salient price variable for egg producers who need to choose between cage-free or conventional hen housing would likely be the price premium of cage-free eggs over conventional eggs. However, most countries in our sample only publish egg prices averaged over all different types of hen housing methods. To the best of our knowledge, only the US [58] and the United Kingdom [59] publish prices of cage-free eggs and other egg types separately. Finally, estimating the effect of prices on supply or demand is a well-known difficulty [60, p3]. Because price is the mechanism that regulates any given market, price variables suffer from feedback loop problems when included in causal estimations of supply or demand variables such as the percentage of cage-free hens. Methods to resolve these issues require data on the problematic variable; since we are unable to obtain

this data, we are not able to include price premium in this study.

3.2. Data

3.2.1. Percentage of hens in cage-free housing Data on the percentage of hens living in cage-free housing by country and year will be collected from egg industry and government publications. We have identified egg industry publications that report hen housing and other egg production data on an annual basis for several countries as well as government reports for the US [8] and EU [61]. International trade between countries with high numbers of corporate commitments and low domestic production of eggs may affect our hypothesis that corporate commitments from food businesses with operations in a particular country increases the percentage of cage-free housing in that same country. However, nearly all the countries in our sample are largely self-sufficient in egg production.⁵ Germany is the only country with both a low self-sufficiency rate and a high number of corporate commitments.⁶ To avoid confounding our estimates, we will omit Germany from our study.

3.2.2. Corporate commitments and pressure campaigns

Corporate commitment and pressure campaign data are obtained from ChickenWatch.org [7], a website that tracks

⁵ Egg industry reports include a “self-sufficiency rate” which is defined as the ratio of domestic production to domestic consumption (i.e., production minus exports plus imports) [62].

⁶ See Windhorst [63] for a detailed analysis of the spatial shifts in EU egg production, with a special focus on the German case study, during the period following the EU’s ban of battery cages.

food business commitments to source higher welfare animal products, including cage-free eggs. The data are input by the animal advocacy groups that secured each commitment, with a dedicated administrator reviewing the data. Each observation records details about a single publicly stated commitment, including corporation name, industry (retailer, restaurant, producer, etc.), date on which the commitment was published, deadline for compliance, countries covered, and whether the commitment was obtained through dialogue or a pressure campaign. Note that commitments may not be one-to-one with corporations or legal entities: for example, a commitment might represent only a single brand or subsidiary of a larger corporation. While this produces some inconsistency in the unit of analysis, there is no obvious source of systematic bias.

Ideally, these data would be used to estimate the percentage of egg demand committed to be sourced from cage-free hens. However, estimating the demand of a particular corporation is not usually possible, although limited data are available for the US [44]. For this study, the commitment data will be aggregated to count the number of commitments made in a given year for a given country. Thus the current data are limited in that they weight each commitment equally, when in fact the number of eggs demanded by different corporations varies widely [44].

3.2.3. Legislation Information for the legislation variable will be collected from public news sources and communication with experts on the subject. We choose an indicator to implement the legislation variable rather than, for example, a composite index to simplify data collection and model specification in this analysis, where legislation is not the main effect of interest.

3.2.4. Influenza We will collect avian influenza (AI) data on the cumulative number of egg-laying hens killed as a result of AI in a country and year from publications in public health, epidemiology, and veterinary science [64]. Alternate sources of data include the European Food Safety Authority (EFSA) and USDA publications on the history of highly-pathogenic AI outbreaks in their respective countries. These data are likely to be more aggregated. For example, the EFSA quarterly updates published the number of outbreaks, rather than the number of birds in each outbreak, in the 19 member states affected by the H5N8 strain from 2016–2017. In the absence of ideal data, we will use either the country-level cumulative number of AI outbreaks as of 2016 [64] or an indicator variable for whether

the country experienced a severe outbreak of AI in the current or past years.

3.3. Instrumental variables

Identification of the causal relationship between corporate commitments and the percentage of hens in cage-free housing using observational data is at high risk of statistical bias. *Confounding bias*, which occurs when the intervention shares a common cause with the outcome, is the primary concern in our study. *Endogeneity* describes several situations that may lead to confounding bias such as unobserved (i.e., omitted) variables, causal feedback loops (i.e., *simultaneity bias*), or measurement error. We discuss the issues that potentially affect our study—namely unobserved variables and causal feedback loops—and the modeling choices we make to account for those issues.

Endogeneity from causal feedback loops arises when multiple actors make decisions that affect the same set of variables, and therefore determine the outcome of those variables, at the same time. We suspect that corporate commitments may be simultaneously determined with cage-free housing. This study investigates the hypothesis that the percentage of hens in cage-free housing is partially caused by the number of corporate commitments; in other words, egg producers consider corporate commitments when making decisions about hen housing. However, the number of corporate commitments may itself depend on cage-free egg production, since corporate decisionmakers likely consider the existing availability of eggs from cage-free hens when deciding to commit.

When these two variables are simultaneously determined, we can show that the endogenous variable *cumulative_commitments_{it}* is correlated with the error term in the equation that determines the percentage of hens in cage-free housing. Consider a rewriting of the empirical model given by Equation 1 in more compact notation:

$$y_{it} = \beta_0 + \beta_1 Y_{it} + X_{it} \mathbf{B} + v_i + u_{it} \quad (1)$$

where

- $y_{it} = \text{perc_hens_cage_free}_{it}$;
- $Y_{it} = \text{cumulative_commitments}_{it}$;
- $X_{it} = [\text{legislation}_{it}, \text{flu}_{it}, t]$ is a vector of the exogenous variables (that is, observed and not endogenous); and
- $\mathbf{B} = [\beta_2, \beta_3, \beta_4]$ is a vector of coefficients to be fit alongside coefficients β_0 and β_1 .

As before, the country-level error (v_i) accounts for unobserved variables like consumer preferences that may be correlated with both the cumulative number of commitments (Y_{it}) and the percentage of cage-free hens (y_{it}). This equation represents the main decision of interest in this study, namely the producers' decisions of how to house hens. However, we can also model the corporations' decisions as,

$$Y_{it} = \delta_0 + \delta_1 y_{it} + \mathbf{W}_{it} \mathbf{D} + \epsilon_{it} \quad (2)$$

where \mathbf{W}_{it} is a vector of any exogenous variables affecting Y_{it} , and δ_0 , δ_1 , and \mathbf{D} are coefficients of this relationship. Combining Equations 1 and 2 as,

$$Y_{it} = \delta_0 + \delta_1(\beta_0 + \beta_1 Y_{it} + \mathbf{X}_{it} \mathbf{B} + v_i + u_{it}) + \mathbf{W}_{it} \mathbf{D} + \epsilon_{it} \quad (3)$$

we can see that u_{it} affects Y_{it} and therefore violates the assumptions of ordinary least squares estimation that all explanatory variables are uncorrelated with the error term.

Instrumental variables estimation is a standard solution to correct for simultaneity bias in linear regression. The method relies on a relationship between an instrumental variable and the endogenous explanatory variable to help account for the additional influence of the feedback loop on the outcome variable. An instrumental variable must adhere to two criteria: it must be correlated with the endogenous variable, yet it must be uncorrelated with the outcome variable aside from its effect on the endogenous variable. We suggest that public pressure campaigns are a conceptually appropriate instrumental variable for corporate commitments. As discussed in Section 2.3, animal advocacy groups widely believe campaigns are a cause of corporate commitments. Furthermore, pressure campaigns have been implicated as playing a role more generally in obtaining corporate commitments to improve animal welfare (Section 1.1). Since public pressure campaigns are not run against egg producers, which are rarely well known among the public, campaigns are not directly correlated with changes in hen housing. Where possible, we will test for the validity of this instrumental variable, as described in Section 3.5.

We define *cumulative_campaigns_{it}* as the cumulative number of public pressure campaigns run by advocacy

groups in country i by year t .⁷ We'll use two-stage least squares regression for estimation. In the first stage, the endogenous variable (cumulative number of commitments, Y_{it}) is regressed on the instrumental variable *cumulative_campaigns_{it}* and the exogenous variables (\mathbf{X}_{it}) from Equation 1. In the second stage, the residuals from the first regression are included in the main regression of the percentage of cage-free hens on the number of commitments and other explanatory variables, to control for the unobserved relationship between commitments and housing.

3.4. Model specifications

We can use models for longitudinal data in conjunction with an instrumental variable to address both simultaneity bias and omitted variable bias, both of which lead to endogeneity and confounding bias. Omitted variable bias arises when the omitted variable is correlated with one of the explanatory variables as well as the dependent variable; that is, the relationship between the main explanatory variable of interest and the dependent variable is driven in part by a third, unobserved variable. To illustrate within the context of this study, unobserved consumer preferences may influence corporations' willingness to make commitments as well as the percentage of cage-free hens. Suppose consumers prefer cage-free eggs: then producers may be more willing to house their flocks cage-free while, at the same time, food corporations are more willing to commit to sourcing the cage-free eggs that their customers prefer. Similarly, the price premium between cage-free and conventional eggs is unobserved yet may influence the percentage of cage-free hens as well as commitments. The best solution to omitted variable bias is, of course, to include the omitted variable in the estimation procedure. However, when data are unavailable the impact of this bias must be mitigated with statistical tools.

Fixed and random effects models are most commonly used for longitudinal data. Both are special cases of a general CRE or hybrid model. The general CRE model seeks to separately estimate both the effects within an individual over time (the *within* estimator) and between individuals at

⁷ The relationship between campaigns and commitments is not one-to-one: while the majority of pressure campaigns ended with corporations committing, a very small number of campaigns were abandoned without earning a commitment. Other commitments were prompted by dialogue with animal advocacy groups or internal company initiatives. However, the instrumental variable technique requires instruments to be highly, but not *perfectly*, correlated with the endogenous variables to reduce simultaneity bias [65].

a fixed point in time (the *between* estimator).⁸ Each model specification presents different assumptions and benefits.

The fixed effects model allows us to remove time-constant country-level unobserved variables like a country’s preferences for cage-free eggs or eggs in general by subtracting the means over time from all variables, a process known as the within transformation.⁹ This procedure is beneficial because it removes the unobserved country-level effects without placing distributional assumptions on them; however, the specification also implies that observed and potentially important time-invariant (or almost time-invariant) variables like legislation will also be removed from the estimation.¹⁰ If the underlying data-generating relationship between the dependent variable and explanatory variables is nonlinear, the fixed effects estimator will be biased; however, this bias may be a small price to pay for the relatively few assumptions on distribution and the computational ease of the estimation procedure, especially when combined with two-stage least squares estimation to handle simultaneity bias. Although not the primary bias of concern in this study, we can specify standard errors to be clustered at the country level to allow for correlation over time between repeated measures of the variables.

In the first-stage regression of the fixed-effect specification, the endogenous variable is regressed on the instrumental and exogenous variables. For concision, we’ll combine the latter as a vector $Z_{it} = [cumulative_campaigns_{it}, X_{it}]$. We denote the within transform, which subtracts the average over time of a variable within a country, by adding a tilde. Applied to Z_{it} , the within transformation yields $\widetilde{Z}_{it} = Z_{it} - \frac{1}{T} \sum_{t=1}^T Z_{it}$, where T denotes the number of years of data. Thus the first-stage regression follows as,

$$\widetilde{Y}_{it} = \widetilde{Z}_{it}\alpha_1 + \widetilde{\epsilon}_{it} \quad (4)$$

Fitting this regression yields the residuals, $\widehat{\epsilon}_{it} = \widetilde{Y}_{it} - \widetilde{Z}_{it}\widehat{\alpha}_1$, where $\widehat{\alpha}_1$ is the estimate of α_1 . This coefficient is used only to calculate the first-stage residuals and test the relevance

⁸ See Bell [66] and Schunck [67] for mathematical derivations of each model and detailed discussion of the connection between the models and the different estimators.

⁹ Though preferences may change over time, national preferences may be slow enough to change so that this variable may be considered “almost time-invariant” and therefore subject to the same removal from the estimation model [68].

¹⁰ Bell [66] further argues that removing time-constant effects from the model is itself a strong assumption on the connection between the group-level unobserved variables and the dependent variable.

of the instrument.

The second-stage regression is derived by first applying the within transformation to Equation 1. This transformation removes the unobserved variables v_i and the intercept β_0 . Adding a term for the residuals of the first-stage regression (and a coefficient, β_5) gives the fixed-effects model specification,¹¹

$$\widetilde{y}_{it} = \beta_1 \widetilde{Y}_{it} + \widetilde{X}_{it}B + \beta_5 \widehat{\epsilon}_{it} + \widetilde{u}_i \quad (5)$$

where β_1 is the coefficient of interest.

While the fixed effects model estimates the within relationship, we are also interested in the between relationship. The random effects model explicitly includes the country-level effect but assumes that the country-year-level and country-level explanatory variables are uncorrelated, which may be too strong in certain contexts. Additionally, the random effects estimator combines both the within and between effects without independently identifying either. However, using algebraic transformations and assumptions about the distribution of unobserved variables conditional on observed independent variables, the CRE model generalizes the estimators of both the fixed and random effects models. The model allows the country-year-level and country-level explanatory variables to be correlated; identifies the within and between effects in a single specification; tolerates balanced or unbalanced panels; and allows nonlinear specifications.

We follow Papke and Wooldridge [70] and use the Mundlak transformation $v_i = \beta_0 + \overline{Z}_i\xi + a_i$ to rewrite Equation 1 as Equation 7, as well as including the additional term $\overline{Z}_i\alpha_2$ in Equation 6.¹² The two-stage CRE estimation specification is then,

$$Y_{it} = \alpha_0 + Z_{it}\alpha_1 + \overline{Z}_i\alpha_2 + \epsilon_{it} \quad (6)$$

$$y_{it} = \beta_1 Y_{it} + X_{it}B + \beta_5 \widehat{\epsilon}_{it} + \beta_0 + \overline{Z}_i\xi + a_i + u_{it} \quad (7)$$

¹¹ Note that this exposition of the fixed effects two-stage least squares estimator describes the process in a manner similar to the control function process, where the residuals are calculated in a separate estimation step, and then later included in the main estimation procedure. Most modern estimation programs contain packages that calculate the fixed effects two-stage least squares estimator with a single function call or estimator. We will use the R function `fe1m` from the package `lfe` to calculate our estimator with country-level cluster robust standard errors [69].

¹² See Papke and Wooldridge [70] for a detailed exposition of the CRE model with endogenous explanatory variables, including the Mundlak transformation, the model’s assumptions, and interpretation of results.

where

- $\bar{Z}_i = \frac{1}{T} \sum_{t=1}^T Z_{it}$ is the time average of Z_{it} ;
- α_2 and β_5 are coefficients to be fit;
- $\hat{\epsilon}_{it}$ are the residuals from the Equation 6;
- $\bar{Z}_i \xi$ describes the time-averaged country effects of explanatory variables; and
- a_i is the unobserved but uncorrelated country effect.

In this specification, the coefficients of interest are β_1 and ξ . The Mundlak transformation decomposes the within and between effects as the within estimator β_1 and the difference of the within and between estimators ξ [67]. After the transformation, these coefficients should be interpreted as the average partial effects, or the average effect on the outcome variable from increasing the value of an explanatory variable by one for all individual countries in the population [71].¹³ The decomposition motivates the modified Hausman test for endogeneity of the country-level effects (or the test to choose between the FE model and the CRE model) using the null hypothesis $\xi = 0$ [72].

The flexibility of the CRE model also allows us to use either linear or nonlinear specifications of the relationship between the outcome variable and the explanatory variables. A linear specification has the advantage of a more straightforward computation during the estimation procedure; however, since the linear specification does not restrict the outcome to between 0% and 100%, it may yield nonsensical predictions. On the other hand, a nonlinear specification allows for estimates that provide realistic predictions, but common nonlinear specifications like the probit model may have difficulty converging during the estimation procedure. To estimate the nonlinear specification, we follow Papke and Wooldridge [70] and use a generalized estimating equation (GEE) with a pooled probit option.¹⁴ The control function instrumental variable process will be achieved by estimating the first-stage relationship between the endogenous variable Y_{it} and the instrument *cumulative_campaigns_{it}* and other exogenous variables, pooled across time periods; calculating the residuals; and finally including the residuals in the probit GEE of y_{it} to estimate the coefficients.

¹³ Papke and Wooldridge show that these coefficients are identified for several different specifications of the model, including the linear and nonlinear forms we consider in this study.

¹⁴ We will use the R package *geepack* [73] to calculate both the linear and nonlinear CRE estimators.

3.5. Checks and model selection

We will perform a variety of statistical tests alongside the estimation procedures to check our assumptions about the models and the correlation structures of the data. To confirm the appropriateness of our instrumental variable, we will test the correlation of the instrument with the endogenous explanatory variable. We'll use an F -statistic hypothesis test on the coefficients from the first-stage regression in each model to determine whether the coefficients are jointly statistically different from zero. A large F -statistic will indicate that the first-stage coefficients are statistically different from zero and therefore are relevant instruments. Should we fail to reject the null hypothesis that the effects of the instruments are equal to zero, we will attempt to determine more appropriate instruments (or a more appropriate definition of the campaigns variable) for our analysis. The assumption that the instrument is uncorrelated with the dependent variable cannot be directly tested as there are not more instruments than endogenous variables [74]. Instead, we must rely on our analysis of the strategy and impacts of pressure campaigns on obtaining corporate commitments (see Section 3.3).

For model selection, we will first visually inspect the residuals produced by each model. We will estimate the quasi-likelihood modification of the Akaike Information Criterion (QIC) developed by Pan [75] for GEE models to determine which approach best fits the data, as indicated by a lower QIC value. Additionally, we will test the endogeneity of the country-level variables using the null hypothesis $\xi = 0$; in other words, this procedure tests whether the random effects coefficients are statistically different from the fixed effect coefficients. These tests will ensure that the estimation model is specified to best fit the underlying data-generating process.

Finally, we test the main hypothesis of interest in this study, the impact of corporate commitments on the percentage of hens living in cage-free housing, with the null hypothesis $\beta_1 = 0$. The linear fixed effects estimation function `feImlm` computes the two-sided t -statistic of all coefficient estimates, and the GEE implementation of the CRE models computes the Wald statistic for coefficient estimates.

3.6. Residual risk of bias

To explain our estimation strategy, we have followed a framework for conceptualizing the risk of bias from the Cochrane Handbook for Systematic Reviews of Interven-

tions chapter Assessing Risk of Bias in a Non-Randomized Study [76]. Therein, bias in an observational study is conceptualized as “the systematic difference between the study results obtained from an NRSI [non-randomized study of the intervention] and a pragmatic randomized trial (both with a very large sample size) addressing the same question and conducted on the same participant group, that had no flaws in its conduct” [76, §25.1.1]. Different sources of bias are then classified as *confounding*, *selection*, *information*, and *reporting* biases. We have discussed confounding bias in detail in the sections above; in the following sections, we consider the other residual risks of bias.

We considered the ideal experiment to be randomly assigning different numbers of cage-free commitments to different countries. In this trial, random assignment of commitments would reduce the endogeneity associated with the commitment variable, both by removing the simultaneity bias inherent in the corporations’ decisions to commit and by controlling for the unobserved effects influencing both commitments and housing.

3.6.1. Selection bias Selection bias results from either the systematic exclusion of certain subjects from the study due to factors related to both the treatment and outcome variables or due to loss to follow-up of subjects. Our use of egg industry data for the outcome variable mitigates this concern, due to the consistency of reporting. In particular, annual reports have tracked hen housing in reporting countries since 2007, before most of the corporate commitments were publicized, and few countries have been added or removed since. The countries included in the reports account for the vast majority of the individual cage-free commitments in ChickenWatch.org and over half of countries with commitments. The reports also include countries in which no cage-free commitments have been made. Nonetheless, there remains a risk of bias from the industry’s initial selection of countries, although we believe this risk to be small.

3.6.2. Information bias Information bias occurs where intervention status or outcome data are biased. Since animal advocacy groups are incentivized to publicly promote their successes, commitment data are likely to be entered into ChickenWatch.org; duplication is probably a more significant concern than omission. Duplication of the commitment data will be addressed during the data cleaning process. As noted in Section 3.2.2, because commitments can represent a single subsidiary or brand of a larger corpo-

ration, there is also likely some heterogeneity in the unit tracked by commitments. However, there is no clear source of systematic bias.

Data on which commitments occurred following dialogues or campaigns are potentially missing, and, where possible, all reasonable efforts will be made to complete this data by contacting the relevant parties. Missingness is most likely among the earliest commitments when data collection was less rigorous.

For our outcome data on the percentage of cage-free hens, we will not have detailed information on the industry’s data collection methods. Where possible, we will verify this data against government statistics. Since government statistics usually rely on self-reports from producers, fraud is possible. However, reports of fraud in cage-free housing are not widespread: Mendez [8] notes that reporting of US government cage-free data is voluntary and anonymous, and therefore producers have little incentive to report fraudulent data.

3.6.3. Reporting bias Finally, reporting bias arises from the selective reporting of results and outcomes. We mitigate reporting bias primarily through this preregistration, which publicly explicates our intended outcome measures and analysis plan. This prevents the selective reporting of outcomes and reduces the risk of specification searching, p-hacking, or hypothesizing after the results are known (i.e., HARKing) [77].

4. DISCUSSION AND CONCLUSIONS

This confirmatory study will aim to test the impact of corporate commitments to source cage-free eggs on the percentage of hens in cage-free housing at a national level. We hypothesize that cage-free commitments have positive effects on the percentage of hens living in cage-free housing. Further, we will explore the impact of legislation, which is also expected to have a positive effect. The results of this study may inform activists on how to allocate their scarce resources, producers on how to respond to changing demands from their downstream food business customers, and corporations on the expected impacts of socially responsible policies.

However, we will interpret the results carefully. Our methodology seeks to account for several potential sources of bias, including endogeneity of corporate commitments and known unobserved variables like consumer preferences, but despite our efforts, remaining unobserved vari-

ables may still bias the estimated effects. The national-level aggregation of outcome data or heterogeneous treatment effects could dampen the observed effect of commitments on production. Furthermore, this study only considers current rather than future effects of commitments; the effects of commitments are lagged rather than instantaneous and it may be too soon to see an effect on production in some countries.

Extensions of this model could estimate the relative impact of details of legislation like sales bans and bans on enriched or battery cages. This extension could include more detailed data on hen housing types available in some countries. The interaction of the avian flu mortality rate with the other main explanatory variables could also be further explored. A dynamic model of the relationship between cage-free commitments and hen housing, created by adding lagged explanatory variables to our empirical specification, could be a fruitful extension. Our cumulative definition of key variables preserves the long-term effects of commitments on hen housing; however, the short-term effects of commitments made in nearby periods on housing may interest egg producers and legislators. Finally, spatial-dynamic models might also account for shifts of egg production and trade, which may enable the analysis of cross-border impacts of commitments in countries with very high or very low self-sufficiency rates, like Germany.

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6. DECLARATIONS

6.1. Preregistration

At the date of publication, some data for this project have been obtained and data cleaning for data on corporate commitments and campaigns has commenced. However, besides the US data on cage-free housing and corporate commitments (Figure 1), no data for this project have been substantively analyzed. During a public presentation, one author incidentally saw a graph of increasing cage-free egg production in a Scandinavian country that, to their recollection, supported the main hypothesis of this study. During searches to identify data availability, we examined the cage-free housing and corporate commitment data to assess

which countries and years were available in the data. Examining this incomplete data informed plans for data cleaning and searches for further data, but did not substantively test or inform any of our preregistered hypotheses.

6.2. Conflicts of interest

Samara Mendez and Jacob Peacock are affiliated with The Humane League Labs (THLL). THLL performs scientific research to inform animal advocacy strategy. THLL is a program of, and currently fully funded through, The Humane League (THL), a 501(c)(3) nonprofit organization that “exists to end the abuse of animals raised for food.” THLL is editorially independent from THL, and any other potential funders, in reporting research results. The design, execution, analysis, interpretation, and reporting of THLL research is performed entirely by THLL staff, without oversight by other THL staff or leadership. To further mitigate potential conflicts of interest, THLL demonstrates commitment to transparency by adhering to open science practices, including public preregistration of studies and analysis plans as well as publication of supporting data, computer code, and materials for all THLL research.

Matt Butner declares no conflicts of interest.

6.3. Authors' contributions

Jacob Peacock and Samara Mendez conceptualized the project. All authors developed the methodology. Samara Mendez led manuscript writing. All authors reviewed and approved the final manuscript.

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