The Chick or the Egg Price: Unpacking the Economic Impact of Germany's Chick Culling Ban

Abstract

In 2022, Germany was the first, and to date the only country that outlawed the routine culling of chicks, a standard practise in the egg industry. This thesis examines the impact of Germany's chick culling ban (CCB) on consumer egg prices and industry outcomes, through time-series analysis using data from 2015 up to and including 2023. By employing an ARDL model and forecasting techniques, this study finds an average 10 to 15 percent egg price increase in the two years following the ban. The price increase was most pronounced shortly after the ban's implementation, which lead to a strong initial price increase, after which the effect slowly diminishes over time. For the last observed period, egg prices have almost fully returned to expected prices in absence of the CCB. No significant disruptions to supply were observed, as both egg production and flock size remained stable. This suggest that producers have been able to largely pass off their cost increase onto consumers. The estimated loss in consumer surplus ranges from 750 million to 1 billion in the first two years after the ban went into effect. This approximation may represent the total social cost associated with the ban, provided that the market has fully adjusted to the new legislation after two years.

ERASMUS UNIVERSITY ROTTERDAM

Erasmus School of Economics
Master Thesis Policy Economics

Name student: Rik-Jan Veldhuijzen
Student: ID: 434710

Supervisor: Dr. D. Sisak
Second assessor: Dr. L.C.G. Pozzi

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1. Introduction

The bifurcation of highly specified chicken breeds for egg and meat production has rendered male chicks from laying breeds economically unviable for either industry. These male chicks can neither lay eggs nor compete with specialised breeds for meat production. Consequently, worldwide, the poultry industry annually kills an estimated 6.5 billion just-hatched chicks, 330 million of which are in the European Union (EU) (European Parliamentary Research Service, 2022, Heinemann & Hecquet, 2022).

EU law prescribes two chick culling methods, which ought to deliver an instantaneous and painless death (Council Regulation (EC) No 1099/2009, 2009). Either maceration, where chicks are shredded by a high-speed grinder, or asphyxiation, which typically involves the use of carbon dioxide to gas the chicks, are allowed. However, negligence during maceration practices and respiratory distress associated with gassing mean that in practice, this requirement is not always met (European Food Safety Authority, 2019).

The routine mass culling of chicks is a highly contentious issue that occurs outside of the public eye, leading to a lack of awareness. However, public opinion overwhelmingly condemns the visually disturbing practice of culling chicks upon learning about its realities, with 75 percent of Europeans and 85 percent of Germans deeming it unacceptable (Eurobarometer, 2023). Despite widespread disapproval of chick culling, the issue does not receive much urgency beyond activist circles.

In 2019, activists celebrated a breakthrough win. After a six-year-long legal dispute, the German Supreme Court upheld a regional ban on chick culling, ruling that mere economic reasons are insufficient grounds for the killing of animals. The ruling had major implications, as it undermined the legality of chick culling nationwide. In response, the Federal Parliament passed legislation to prohibit chick culling, effective January 2022 after a short transitionary phase. Germany's leading role is extra significant because it is the largest egg producer in the EU, responsible for approximately twelve percent of all culled chicks. Since then, France, Italy, both among Europe's major egg producers, and Austria have passed legislation to ban or restrict chick culling in the coming years.

Given this current trend, it is plausible that the EU will implement a region-wide ban on chick culling in the foreseeable future. A German French-led proposal for an EU-wide ban on systematic chick culling was co-signed by eight other nations, while a call on the European Commission to conduct an impact assessment on the issue was supported by the majority of countries. EU Commissioner for Health and Food Safety, Stella Kyriakides, outspokenly supports phasing out this ''very disturbing phenomenon'' (European Parliamentary Research Service, 2022). Countries that expressed concerns did not oppose a ban outright but expressed concerns about the cost of such a ban, requesting an evaluation of the ban's socioeconomic impact. These concerns reflect the poultry industry's concern, which calls for time and financial assistance to transition to chick-culling-free egg production.

Amid these potential changes, the need to understand the economic impact of such a ban becomes increasingly urgent. Despite the large potential ramifications of a ban on chick culling, little is known about its impact on the egg industry. This thesis aims to fill this gap by studying the economic consequences of the ban's implementation in Germany, currently the only country to have enforced such a ban. Understanding the impact of the ban in Germany will provide valuable insights for other countries and the EU, helping them make informed decisions regarding their chick-culling policies.

The main research question is: What is the effect of Germany's chick culling ban (CCB) on consumer egg prices? I conduct an ex-post empirical analysis, using time series and forecasting techniques, to estimate the ban's impact. Additionally, I analyse its effect on the laying hen flock size and total egg production to measure the impact on the egg industry. This will provide insight into how social costs associated with the ban are distributed.

By addressing these questions, this thesis will contribute to the broader literature on empirical ex-post evaluations of animal welfare regulation. Economic infeasibility is the main objection cited against stricter regulation. However, due to a lack of interest among economists, there has been little empirical research into its actual impact. By conducting this research, I aim to answer the calls of Lusk and Norwood (2011) and Christensen et al. (2012) for economists to engage more actively in the animal welfare debate and provide insights into the economic impacts of animal welfare regulations.

The remainder of this thesis is structured as follows: Chapter 2 provides the background against which this thesis is understood. It discusses the position of animal welfare in economics, gives an overview of the legal context of the CCB in Germany, and summarizes the existing literature. Chapters 3 and 4 describe the data and methodology of this study, respectively. Chapter 5 contains the analyses and several robustness checks. Finally, Chapter 6 discusses the results, and Chapter 7 concludes.

2. Theoretical Framework and Literature Review

2.1 Animal Welfare in Economics

2.1.1 The Development of Animal Welfare Thought

Over the last decades, animal welfare concerns have moved beyond activist circles and become a topic of mainstream discussion. Especially in Europe, there is growing public recognition of animal suffering. Now, a staggering eighty-four percent of Europeans and ninety percent of Germans think that farm animals in their country deserve better protection (Eurobarometer, 2023).

The modern animal welfare movement traces its origins back to utilitarian philosopher Jeremy Bentham (1789/1996) who argued that the ability to suffer entitles a being to moral consideration. This radical departure from widespread Cartesian views, which denied animals a moral status based on their inability to reason, marks a pivotal moment in moral philosophy.

In the early twentieth century, traditional animal husbandry began to adopt increasingly intensive farming practices. By the end of the century, factory farming had fully replaced traditional methods. This transition changed the relationship between humans and animals from one of cooperation to one of exploitation, at the expense of animals.

Activist Ruth Harrison (1964) and utilitarian philosopher Peter Singer were among the first to bring animal welfare concerns on factory farms to public attention. The current animal welfare movement credits Singer's (1975) Animal Liberation as its foundational text. Scientific contributions to animal welfare have since come from various disciplines, such as biology, sociology, environmental science, and veterinary science.

2.1.2 Development of Animal Welfare in Economics

Despite increasing and multidisciplinary interest in animal welfare, the field of economics has had limited interest in discussing the implementation of animal welfare. Just over thirty papers have been published in the top 50 economic journals, with none published in a leading top 5 journal (Carlier & Treich, 2020).

Economics typically operates under two assumptions: welfarism and anthropocentrism (Johansson-Stenman, 2018). Welfarism asserts that the welfare or utility of all individuals in society determines social welfare, whereas anthropocentrism maintains that only human welfare is significant. Anthropocentrism explains the lack of interest in animal welfare. Economic thought so deeply roots this assumption that it rarely makes it explicit. A notable exception is Baxter (1974), who clearly states: ''My criteria are oriented to people, not penguins. Damage to penguins [...] is simply irrelevant. [...] Penguins are important because people enjoy seeing them walk about rocks. [...] I have no interest in preserving pinguins for their own sake" (p2).

In economics, animals are a production input, not unlike machinery (McInerney, 1993) Animals require inputs, such as food and care, to produce outputs such as meat, eggs, and dairy, but their welfare is only considered insofar as it impacts economic returns (McInerney, 2004). This anthropocentric view considers animals merely instrumental to human well-being.

Despite the neglect of animal welfare in economic analysis, public opinion increasingly challenges farming practices. This shift raises questions about the adequacy of markets for addressing animal welfare issues.

From an economic point of view, animal welfare is a good that can be provided by markets. Market economies rely on prices to reflect the value individuals place on goods. In theory, consumers who are concerned about animal welfare would be willing to pay a premium for animal products produced with higher welfare standards. This mechanism leads to a socially optimal level of animal welfare if markets operate perfectly. However, perfect market conditions are rarely achieved, and various market failures can prevent markets from achieving the desired level of animal welfare. Market failures thus provide economic justification for governments to impose animal welfare regulations, such as the chick culling ban.

2.2 Market Failure

To understand the functioning of markets, it is important to first determine the nature of animal welfare as an economic good. Is animal welfare a private good, valued and consumed by individuals, or a public good, which is valued at a societal level? Under the right conditions, markets can adequately provide private goods, whereas public goods are associated with market failures.

A public good is defined as being non-excludable (i.e. once the good is provided I cannot stop you from enjoying it) and non-rivalrous (i.e., my consumption will not diminish your ability to consume it). Operating a lighthouse is a textbook example to illustrate both characteristics of a public good. The lighthouse provides guiding light to all ships, and its use does not hinder another ship's ability to navigate. Private goods are defined oppositely: they must both be excludable and rivalrous.

Bennett (1995) argues that animal welfare has characteristics of both a private and a public good. Like any supermarket, animal products with higher animal welfare standards are rivalrous and excludable. My purchase of CCF eggs reduces the chance of the next customer buying a carton of eggs, and I control who can and cannot eat my eggs. However, others can rejoice in my consumption of high animal welfare goods. This externality suggests a public good aspect.

Most economists agree with the public good argument. Bennett's observation is repeated by Lusk and Norwood (2011): ''The happiness I derive from eating [chick culling-free (CCF)] eggs does not prohibit you from also being happy at the hen's better life [...] and I cannot keep you from enjoying that I eat [CFF] eggs (p474).'' Cowen (2006) and Harvey and Hubbard (2013) note that the consumption of low animal welfare products creates negative externalities for those who care more about animal welfare and propose to tax low-standard products. Others have developed models to understand heterogeneity in the distribution of these externalities among different groups in society (Espinosa & Treich, 2024; Fleurbaey & Van der Linden, 2021)

In contrast, Mann (2005) argues that animal welfare represents a relationship between the farmer and the animal, making it excludable. Therefore, if a relationship is to be considered an economic good, it should be classified as a private good. Mann acknowledges the negative externalities experienced by animal lovers due to animal maltreatment but argues that so-called psychological externalities alone do not justify government intervention. He believes that recognizing psychological externalities has practical limitations and could lead to a slippery slope toward intrusive policies.

Vetter et al. (2014) offer a dualistic approach, arguing that animal welfare is a public good up until a certain societal threshold, representing a level of animal welfare that all ‘reasonable’ members of society support. Below this threshold, animal welfare becomes a ‘public bad' whose externalities affect everyone. Above this threshold, animal welfare is a private good, whose provision can be organised through markets.

Alternatively, Blandford and Harvey (2014) argue that animal welfare is neither a public good because of its rivalrous and excludable nature nor a private good because of a public duty towards care for animals. Instead, they dub animal welfare a moral good and advocate for a mixed market-regulatory approach but avoid discussing the direct implications of this classification. Lagerkvist et al. (2011) suggest that animal welfare is a merit good that benefits society beyond its willingness to pay. However, for this argument to be persuasive, higher welfare standards should alleviate a sense of collective guilt, which is unlikely. Lastly, Anderson (2011), adopts a radically different approach. He draws a historical parallel between animal welfare and child labour and argues that a duty rests upon society to protect the powerless from exploitation by economic systems, leaving no role for markets.

In conclusion, the categorisation of animal welfare as an economic good is complex because it exhibits traits of a private and public good. Some authors even appeal to moral arguments, suggesting categories beyond private and public goods. However, most economists agree that the public good elements of animal welfare induce market failure, thereby justifying government intervention.

Information asymmetry is another potential source of market failure in animal welfare. Consumer's lack of knowledge of farmed animal welfare prevents them from making informed consumption decisions that align with their values. Similarly, markets will not adequately compensate producers who fail to communicate higher welfare standards to consumers. Reliable animal welfare labels can partially resolve information asymmetry (Alonso et al., 2020; Kitano et al., 2022). However, attributing a monetary value to higher welfare standards may create a commodification of animal welfare, which reduces the intrinsic motivation for animal care, inducing the so-called moral crowding out effect (Mergenthaler & Schröter, 2019).

2.3 Willingness to Pay

Consumer benefits are measured by the consumer surplus, which is the difference between the consumer's maximum willingness to pay (WTP) and the price they pay on the market. Consumer's WTP cannot be inferred from market transactions, because it represents the maximum price, they are willing to pay, which is higher than the price they actually pay. Therefore, WTP studies are a frequently used tool to gauge consumer preferences. Such analyses have been conducted on Dutch and German consumers of CCF eggs.

Leenstra et al. (2011), studying Dutch consumers, find that roughly one in five participants would not be willing to pay more for CCF eggs, while more than half would pay 5 to 10 euro cents more for CCF eggs. This corresponds to a 25 to 50 percent price premium. Roughly 1 in 5 participants said that they would pay double the price or more. De Haas et al. (2021) corroborate this finding, finding that the majority of participants are willing to pay more than twice as much for CFF eggs. De Haas's study warrants some scepticism as 40 percent of the participants reported being vegetarian, a non-representative sample of the Dutch population.

Reithmayer and Mußhoff's (2019) study on a German population finds broad approval for CFF eggs, yet strong heterogeneity in WTP for them. Remarkably, a segment of 28 percent of participants proved completely price inelastic, willing to pay whatever it takes for CFF eggs. Additionally, 27 percent of participants were willing to pay €5.22 for a box of ten CFF eggs, which even exceeds the market price of high animal welfare eggs by a wide margin. Another 21 percent were willing to pay an additional 41 euro cents, while the most frugal group reported a WTP of 16 euro cents for a box. Reithmayer et al. (2021) found that showing people pictures of chicks increases the stated WTP for CFF eggs. In another survey studying the preferences of German consumers for alternatives to culling, most participants stated that they were willing to pay a surcharge for eating in good conscience (Brümmer et al., 2018).

According to these studies, most respondents disapprove of chick culling and are willing to pay a significant price premium to end it. However, if their willingness to pay reflects their actual purchasing behaviour, egg producers would naturally transition to a culling-free system, incentivised by the premium consumers are willing to pay, negating the need for a CCB. Therefore, it is plausible that the WTP in these studies is overstated relative to their actual consumption choices.

Biased estimates in WTP studies are a well-documented phenomenon (Schmidt & Bijmolt, 2020). WTP for *moral goods*, such as animal welfare, are especially prone to bias, as participants often overstate their willingness to pay to align with socially desirable behaviour or to reinforce their self-image as a virtuous person (Kahneman & Knetsch, 1992) This leads to a divergence between real and hypothetical WTP (Bennett et al., 2002; Johansson-Stenman & Svedsäter, 2012; Lusk & Schroeder, 2004), a pattern known as the attitude-behaviour gap (Homer & Kahle, 1988; Vermeir & Verbeke, 2006). Gracia et al. (2009) note that any study on animal welfare improvements finds a significant positive WTP, irrespective of the size and magnitude of the specific measure. Similarly, Lusk and Norwood (2012) find that the respondent's WTP shows limited sensitivity to the number of animals affected. Thus, respondents appear to value the concept of animal welfare rather than specific interventions, leading to an overstatement of their actual WTP.

2.4 Legislative Change in Germany

Germany has a long tradition of animal protection. The *Tierschutzgesetz* (Animal Protection Act) came into effect in 1972. It recognises the intrinsic value of animals and holds that ''no one should cause pain, suffering or harm to an animal without reasonable cause''[1]. In 2002, the German Constitution explicitly incorporated animals into Article 20A, establishing animal protection as an official state goal. The embedment of animals in law created the foundation for animal rights activists to pursue stricter animal welfare regulations.

The debate around chick culling has roots extending at least as far back as the early 2000s when animal rights activists challenged the culling of chicks. As early as 2001, the *Tierschutzbericht* (Animal Protection Report) questioned the legality of killing chicks based on sex. In the following years, ethical concerns regarding the mass killing of chicks gained traction. Subsequent initiatives by several states, including Hessen in 2006 and Niedersachsen in 2011 sought to restrict chick culling, while Nordrhein Westfalen was the first state to announce a ban on chick culling in 2013. Hatcheries subsequently challenged this decision in court, after which a long legal dispute ensued. The opposition claimed that banning chick culling would put their businesses at a competitive disadvantage, as no economically viable alternative was available at the time. Moreover, hatcheries questioned whether the ban was a proportionate response to the issue at hand, claiming that the economic impact of a ban outweighs animal welfare concerns.

The Low Administrative Court sided with the hatcheries on both arguments, stating that the CCB was disproportionate and maintained the economic interests of hatcheries above the interests of animals. The court also pointed out that the legal framework does not currently prohibit chick culling. After the state's appeal, the case ultimately reached the Federal Administrative Court of Germany in 2019, which overturned the lower court's decision and upheld Nordrhein Westfalen's ban, allowing chick culling only on a transitional basis.

The Federal Court's decisions set a significant precedent for the legal status of animals for two reasons. Firstly, the court established that the *Tierschutzgesetz* provided sufficient legal justification for the ban. Secondly, the court presided over the idea that the interests of animals can take precedence over mere economic interests.

The court's ruling paved the way for implementing a nationwide ban on chick culling. The *Bundestag* (Federal Parliament) had previously rejected a proposal for a ban in 2016, but in 2021, they voted in favour of the cabinet's draft law prohibiting chick culling, which became effective in January 2022.

Germany became the first country to ban chick culling after passing this law. Germany's leading role accelerated the debate in other European countries. In February 2022, France passed legislation aiming to ban the routine use of chick culling in the egg industry by 2023 while allowing for exceptions in other industries. The ban was later suspended due to slower-than-anticipated technological advancements in in-ovo sexing, the primary alternative to chick culling. Italy was the third country to ban chick culling, with the ban scheduled to go into effect in 2026. Austria banned the purposeless culling of chicks but allowed chicks to be culled for zoo animal food, which constituted 70 percent of Austria's culled chicks (Hoepke, 2021). Switzerland has not passed any legislation to restrict chick culling, but the egg industry is voluntarily transitioning towards chick-culling-free egg production.

2.5 Supply Chain

The supply chain for eggs is compartmentalized into multiple stages to improve its efficiency. Figure 1 illustrates each stage in a flowchart. The process begins with primary breeding companies, which select desirable genetic traits in the so-called grandparent stock. The grandparents produce a generation of parent animals, which are used to produce commercial laying hens. At each stage, roughly one hundred times more multiplication occurs, making grandparent stock one percent of parent stock and 0.01 percent of the commercial hen's flock size (Fernyhough et al., 2020)

Fertilized eggs from parent animals are incubated in special hatcheries, where they hatch into chicks. This stage marked the separation and culling of male chicks before the prohibition of chick culling. After hatching, the chicks are reared in a different facility for approximately 21 weeks, at which age they are capable of laying eggs. Next, the hens are purchased from laying farms, where they are used for their productive lifecycle of 15 to 24 months.

Understanding the supply chain provides insight into how the CCB impacts egg production. It only has a direct impact on hatcheries, which must adopt alternative methods to prevent chick culling. At this stage, the supply is highly concentrated, with only a dozen enterprises delivering hens for nearly two thousand laying farms. This concentration makes the transition to chick culling-free production more manageable, as investments in alternative technology are only required from a small number of hatcheries instead of all laying farms.

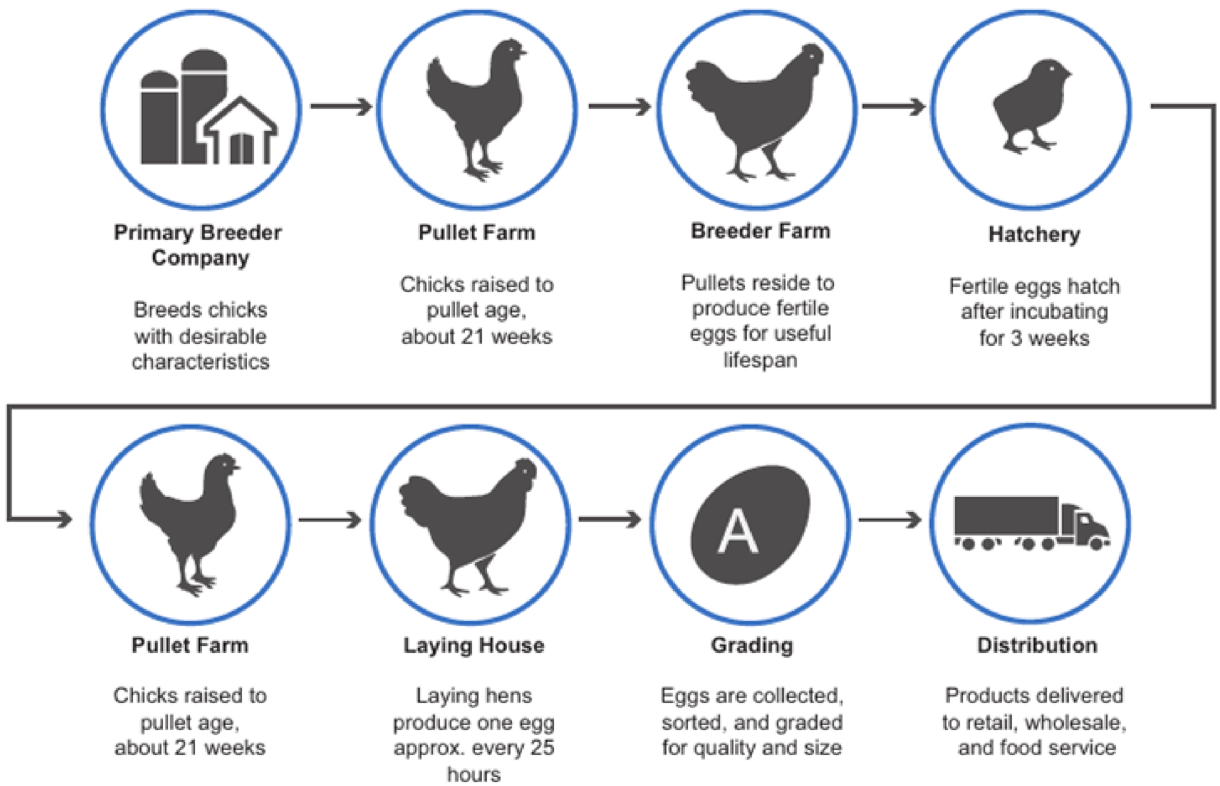


Figure 1: Egg Supply Chain. Source: Pullman and Wu, 2021

2.6 Alternatives to Chick Culling

Two alternatives to chick culling currently exist: (i) raising male chickens for meat and (ii) preventing male chicks from hatching. Raising male chickens can be divided into two categories: (i) brother roosters and (ii) dual-purpose breeds.

Brother roosters, also known as laying cockerels, are male chickens of the laying breed. Fattening laying cockerels for meat is economically disadvantageous due to a slower growth rate and a lower food conversion rate (Damme & Ristic, 2003; Murawska & Bochno, 2007), especially in a time of drastically increasing feed costs. Moreover, laying cockerels require more accommodating housing due to more active and aggressive behaviour (van Niekerk & Workamp, 2022). Due to these extra costs, brother roosters serve a niche segment of the market for high-quality animal welfare products but fail as a large-scale alternative to chick culling (Heinemann & Hecquet, 2022).

The second way to raise male chickens is to shift away from specialised laying breeds to dual-purpose breeds. Dual-purpose breeds are hybrids, with better fattening performance at the cost of reduced egg-laying performance. Currently, dual-purpose breeds lay 10 to 27 percent fewer eggs (Baldinger & Bussemas, 2021; Nolte et al., 2020) than laying breeds and need between two and six weeks more to achieve a market weight (Siekmann et al., 2018; Tiemann et al., 2020). Despite their underperformance in both categories, dual-purpose breeds have the advantage of utilizing both male and female chickens, providing a viable alternative to chick culling.

In-ovo sex determination is an innovative technological solution to chick culling. By identifying and terminating male chickens during the embryotic stage in the egg, it prevents them from hatching. The announcement of Germany's chick culling ban sparked both commercial and state investment into in-ovo sexing technologies, leading to rapid advancements in recent years.

Researchers have developed a variety of in-ovo sexing methods, including DNA or hormonal analysis, as well as optical techniques for detecting molecular and biochemical differences between males and females. For an overview of the current state of technology, I refer the reader to Corion et al. (2023) and Jia et al. (2023).

Germany's chick culling ban initially included the protection of seven-day-old embryos because the pain perception of embryos was believed to develop on the seventh day when the multisynaptic reflex arches close (Rosenbruch, 1997). This proved disastrous for in-ovo sexing technologies, which currently cannot produce reliable sex determination before the seventh day. Germany later relaxed the rules limiting in-ovo sexing to 13 days instead. The motivation for the extension was partly to meet the state of technologies but was also supported by new scientific insights (Kollmansperger et al., 2023; Süß et al., 2023) which established that neurosystem development, a prerequisite for pain reception, only begins after 13 days, providing further ethical justification for the extension.

Following the CCB's implementation, an estimated 70 percent of male laying chicks reached maturity, while 30 percent were in-ovo-sexed, due to a lack of large-scale availability of in-ovo sexing technology (Heinemann & Hecquet, 2022). By 2024, the numbers had reversed, making 70 percent of the hen population in-ovo sexed (Innovate Animal Ag, 2024), proving in-ovo sexing the preferred solution to avoid chick culling.

In the past few years, the cost of ovo-sex determination has been on a downward trend. In 2020, the cost exceeded €4.00 per male bird; by 2022 this improved to €3.50, and by 2024 it had further decreased to €3.10. At the same time, error margins have decreased from 5 percent to less than 1 percent (Global Ag Media, 2024). With an average lifetime production of 350 to 600 eggs per bird, the cost comes down to less than 1 cent per table egg. In the near future, in-ovo sexing technologies may prove economically advantageous, as they may outperform post-hatching sex selection, and hatcheries can dispose of valueless eggs earlier during the incubation period. Seven European countries have adopted in-ovo sexing for commercial purposes as of 2023 (Innovate Animal Ag, 2024). As a result, in-ovo sexing has reached a market penetration of 15 percent in the EU, only five years after its first adoption for commercial use (Innovate Animal Ag, 2024).

2.7 Conceptual Economic Framework

Economics assumes businesses operate in a profit-maximizing way. Before the passing of the CCB, chick culling occurred because it was the most economical way of dealing with male chicks. The CCB's implementation means a deviation from this profit-maximizing equilibrium, forcing the industry to switch to a less efficient production method. As a result, production costs are expected to rise following the ban's implementation. As illustrated in Figure 2, a negative supply shock leads to an upward shift of the supply curve from *Supply* to *Supply**. As a result, prices increase from P to P*, and the quantity of eggs sold reduces from Q to Q*. The consumer surplus is marked in blue. The CCB's loss of consumer surplus resulting from the negative supply shock is highlighted in blue. The total loss of consumer surplus depends on the sensitivity of consumers to price changes. Highly elastic demand means consumers are very responsive to price changes, and a price increase will induce a significant reduction in consumption. In contrast, inelastic demand means that consumers are insensitive to price changes, keeping their consumption equal regardless of price. Graphically, a steeper slope of the demand curve generally indicates more inelastic demand, while a flatter slope indicates more elastic demand. For perfectly inelastic demand, the demand curve is vertical, indicating that the quantity demanded does not change at all in response to price changes. For many households, eggs are a staple food item that lacks close substitutes, which suggests inelastic demand. Recent empirical evidence from the US (Bakhtavoryan et al., 2021) and Eastern Europe (Petrauskaitė-Senkevič, 2020) supports low price elasticity for eggs, while previously discussed WTP studies in Germany reported price insensitivity for large segments of the population. Therefore, egg producers can likely pass on increased production costs to consumers without experiencing a significant decrease in demand. This means that the burden of the cost increase will largely fall on consumers, while producers can maintain their profit margins despite additional costs.

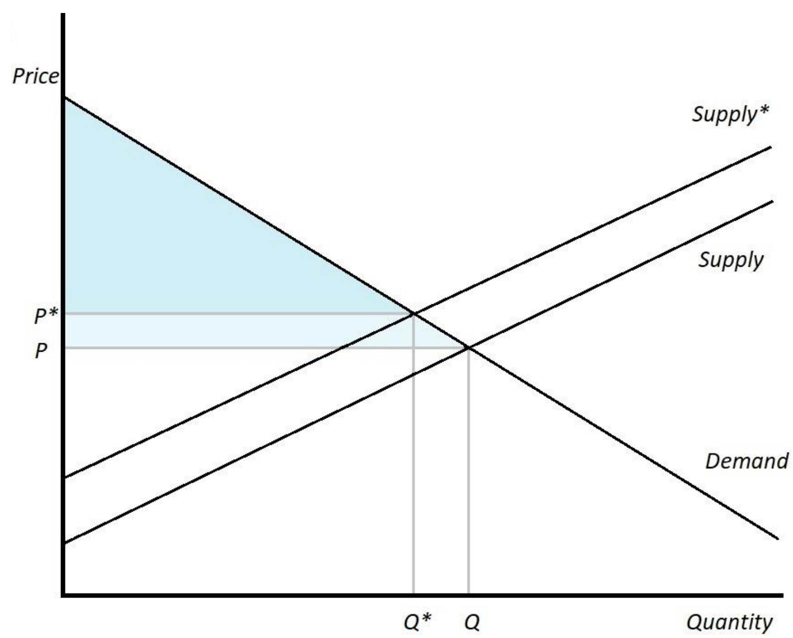


Figure 2: Effect of a Supply Shift Caused by Implementation of CCB

2.8 Empirical Literature Review

There is a limited body of ex-post empirical analyses of animal welfare regulation. To the best of my knowledge, only two relevant studies exist: Malone and Lusk (2016) and Mullally and Lusk (2018). Both studies evaluate the impact of California's ban on battery cages under Proposition II for laying hens on egg prices.

Using price data reported by the USDA, Malone and Lusk (2016) employ a difference-in-difference design to compare egg prices between California and other US states before and after the law was implemented. Moreover, they employed a vector autoregressive model (VAR) to forecast counterfactual prices that would have been expected in the absence of the new regulation. They found a price increase ranging from 33 percent to 70 percent, as well as a 35 percent decrease in egg production, depending on the method used. The annual reduction in consumer surplus was estimated to be between $400 million and 850 million.

Mullally and Lusk (2018) adopt a similar approach, applying forecasting methods to time-series data to estimate the impact of the battery cage ban. They also report a 35 percent decrease in egg production and the number of laying hens kept. Their study differs from Malone and Lusk's in that they use detailed retail scanner data to calculate egg prices. They find an initial 33 percent price spike, which comes down over time to just a 9 percent increase five years after the ban's implementation. Consequently, estimated welfare losses are significantly lower, totaling $117 million.

Both studies demonstrate that stricter animal welfare regulations can significantly affect egg production and price. Proposition II mandated comprehensive changes in production methods, requiring laying farms to either modify their cages or switch to alternative housing methods. In contrast, Germany's CCB does not necessitate substantial changes in business practices, allowing continued operations with different breeds of chickens or the use of in-ovo sexing. Consequently, the CCB is expected to have a less severe impact on the egg industry compared to Proposition II.

3. Data

The main dependent variables are egg price, flock size, egg production, and yield. The European Commission's DG Agriculture and Rural Development provides data on egg prices. The original data consists of weekly observations, which I have transformed into monthly averages to match the frequency of other available data. Prices are expressed in euros per 100 kilograms. Monthly data on laying hen flock size, egg production, utilisation rate, and yield are obtained from the German Federal Statistical Office (GFSO). The GFSO differentiates flock size data at the company size level, enabling a further heterogeneity analysis of the effects of the CCB based on farm size.

The main control variables account for egg production costs. Chicken feed makes up 50 to 70 percent of the total variable production costs of eggs (van Horne & Bondt, 2006; Wollaston, 2023). Other main costs are the purchase of the hen (20 percent), housing (10 percent), labour (8 percent), and energy (5 percent), with the remainder spent on various miscellaneous costs (van Horne & Bondt, 2006; Ibarburu et al., 2019). Therefore, I control for feed prices, energy prices, and labour costs. For both practical and methodological reasons, I exclude housing costs from the pool of covariates. Housing costs are excluded from the covariates because of the lack of a good proxy.

Because housing costs are invariable in the short run, they do not impact the marginal cost of egg production, and therefore I expect no immediate effects of housing costs on egg prices, making it acceptable to not include them in the analysis. Finally, I do not include a control for hen prices. The CCB directly affects hen costs, resulting in higher production costs for egg farms. Controlling for the cost of hens would disrupt the causal chain from chick culling to egg price.

No price data for chicken feed could be obtained directly. Therefore, I approximate the cost of chicken feed based on the price of its main ingredients: soy and corn[1]. Monthly prices on soy and corn are obtained from Index Mundi. Minimum wages are used as a proxy for labour cost, as no industry-specific wages could be found. To account for energy costs, I use wholesale electricity and diesel prices, obtained from Ember Climate Data and the GFSO respectively. Electricity prices are measured euros per kWh whilst diesel prices are measured in euros per hectolitre. Diesel prices represent production cost, where diesel powers farm machinery, and the cost of trade. Lastly, to further account for the cost of trade and the business climate, I control for interest rates, obtained from the GFSO.

Using GSFO CPI data, all prices are indexed to 2015 euros. Table 1 presents the descriptive statistics of the indexed variables. Furthermore, I transform all prices and quantities into logarithms to stabilize the variance, lessen the impact of outliers, and facilitate a more convenient interpretation of the coefficients.

Table 1: Descriptive Statistics

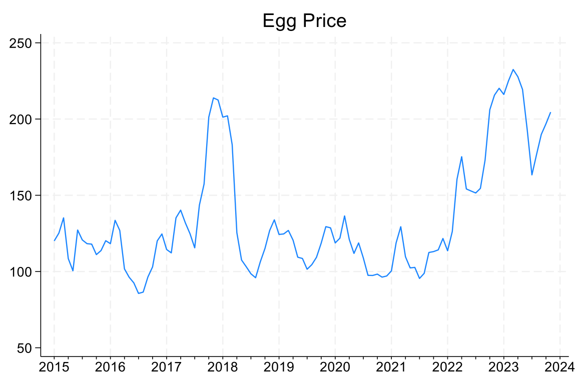
VARIABLES	#Obs.	Mean	Std. dev.	Min.	Max.
Egg Price (€/100kg)	107	134.63	38.52	85.64	232.52
Feed Price (€/100kg)	107	21.72	5.09	15.97	35.19
Diesel (€/100l)	107	99.87	19.41	75.11	162.80
Electricity (€/MWh)	106	65.56	67.07	16.08	416.46
Minimum wage	107	8.96	0.61	8.40	10.60
Interest rate	107	2.10	1.00	1.36	5.27
Daily yield per 100 hens	749	80.65	3.66	73	91
Egg production (x1000)	107	1,045,404	53,658	940,855	1,193,901

Graph 3 depicts the price development of variables over time. In Panel A of Graph 3, a spike in egg prices from August 2017 until March 2018 stands out. This spike may be directly linked to the fipronil scandal. In July 2017, it was found out that many eggs in Western Europe, including Germany, were contaminated with the insecticide fipronil. This led to the removal of millions of eggs from supermarket shelves and the temporary shutdown of egg farms, resulting in a sharp increase in egg prices. After six months, the market stabilized and returned to pre-scandal prices in April 2018. I include a dummy variable for the period of August 2017 to March 2018 to account for the negative exogenous supply shock caused by the fipronil incident.

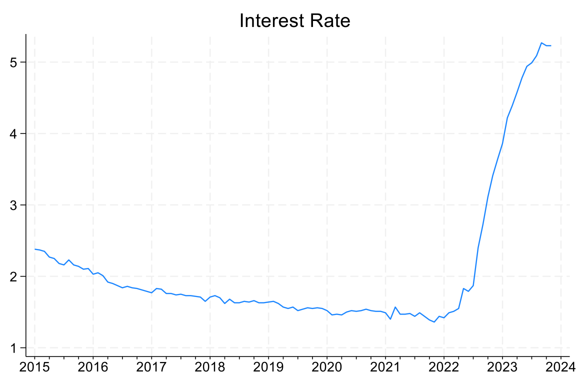
[1] According to the Iowa State University Egg Center, the average composition of chicken feed is 67 percent corn, 22 percent soy, 8 percent limestone while the remaining 3 percent is made up vegetable oils, vitamins, minerals and amino acids. Based on these numbers, Mullally and Lusk (2018) construct a chicken feed proxy as follows: *(0.67/0.89)*corn price + (0.22/0.89)*soy price.* I use the same formula to construct the feed proxy used in this study.

Panels B through F show that the interest rate and all cost variables develop in a similar pattern. From 2015 until 2021 or 2022, prices are characterized by an almost flat, linear, long-term trend, until prices suddenly soar in 2020 or 2021, ultimately slowly decreasing in 2024. These changes can be attributed to troubled economic times following the post-Covid recovery and the Russian invasion of Ukraine in February 2020. Especially the war in Ukraine heavily impacted the main variables of our analysis. The sudden cut-off of Ukraine's agriculture production from the world market resulted in a steep increase in several crops, leading to spillover effects on soy and corn prices. Simultaneously, the EU sanctioned the Russian economy and strongly reduced energy imports from Russia, leading to skyrocketing energy prices in Europe. The impact on Germany, heavily reliant on Russian gas imports, was particularly severe. In response to high inflation, minimum wages were significantly increased, further increasing the cost of egg production.

Panels G through J show the variables related to the production of eggs. All variables exhibit high seasonality, with large fluctuations in flock size, egg production utilisation rate and yield in each year.

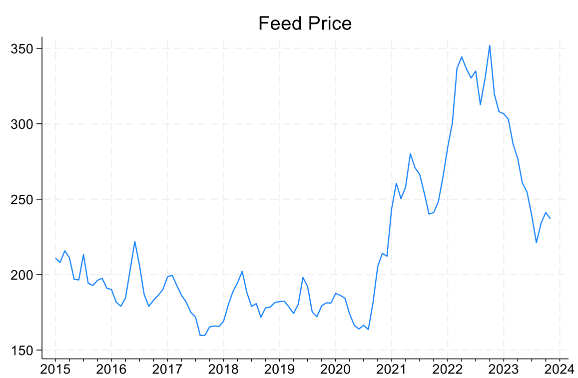


Panel A: Egg Price Development

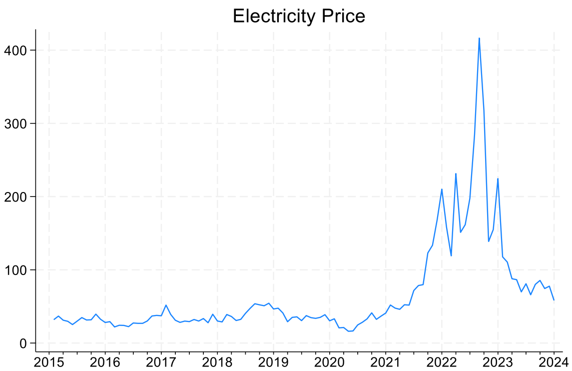


Panel B: Interest Rate

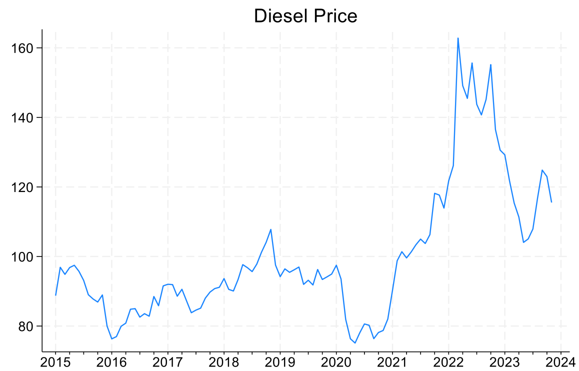
Panel C: Real Hourly Minimum Wage Development



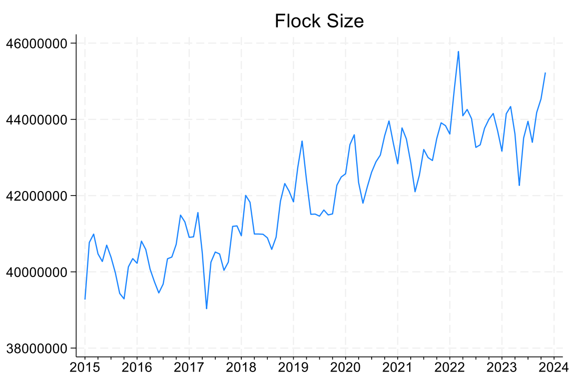
Panel D: Feed Price Development



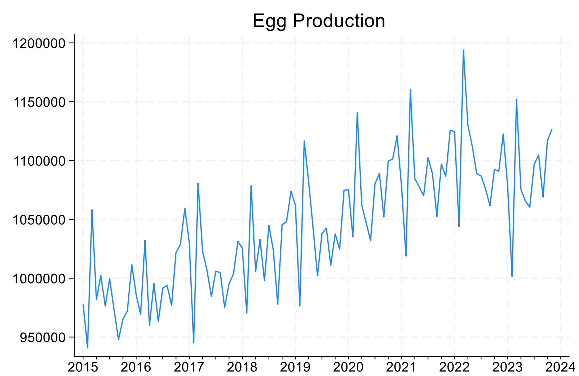
Panel E: Electricity Price Development



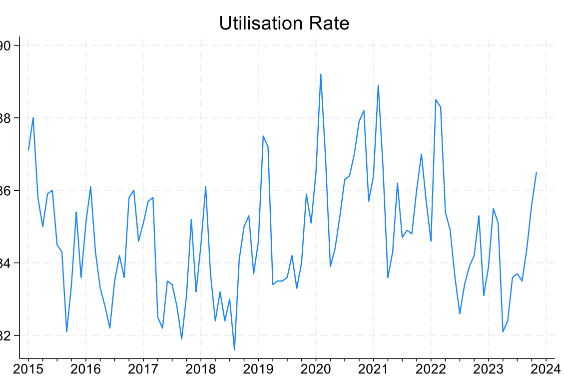
Panel F: Diesel Price Development



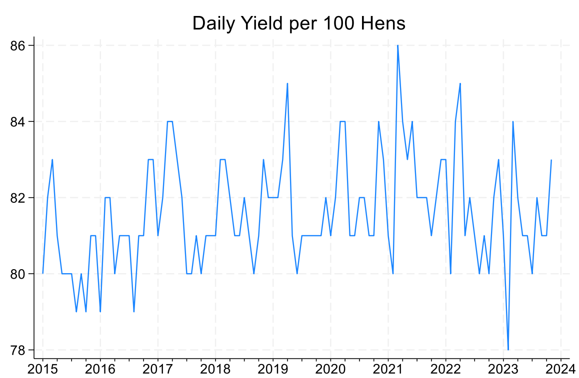
Panel G: Aggregate Average Monthly Flock Size



Panel H: Aggregate Total Monthly Egg Production (x1000)



Panel I: Average Monthly Utilisation Rate per 100 Places



Panel J: Average Daily Yield per 100 Hens

Figure 3: Development of variables over time

4. Methodology

To assess the impact of a policy change, one needs to compare the outcomes under the new regime to what would have happened in the absence of the policy change. The latter outcome, the so-called counterfactual outcome, is a hypothetical scenario. Because it represents what would have happened if the policy had not been changed, it cannot be observed. The impossibility of observing both the actual and the counterfactual simultaneously is the fundamental problem of causal inference.

To address this problem, researchers commonly establish a control group, from which a counterfactual can be inferred. The underlying assumption is that all unobserved factors that could influence our outcomes remain equal over time between the treatment group and the control group. The policy change should be the only factor that changes between the treatment and control group.

For this study, potential candidates for a control group would be neighbouring countries with similar market conditions that have not implemented a CCB. However, Mullally and Lusk (2018), researching the effect of housing regulations for laying hens on egg prices, argue that for their study, the 'all other things equal'-assumption, is unlikely to hold due to trade. They contend that egg shortages, caused by the negative supply shock from such legislation, would likely be offset by imports through international trade. Consequently, the negative domestic supply shock may lead to a positive supply shock abroad, thus undermining the 'all other things equal' condition for the most suitable control group candidates. Countries that are not direct trading partners may be affected by a network of intercountry trade. Moreover, hatching companies in other European countries have voluntarily adopted in-ovo sexing technologies to different extents, offering CCF-free eggs outside of Germany as well, further undermining the *ceterus paribus* condition.

Building on the methods used by Malone and Lusk (2016) and Mullally and Lusk (2018), I use a time-series approach to address the challenges of selecting a suitable control group. Time-series analysis uses self-comparison over time, eliminating the need for a control group and allowing for counterfactual forecasting. In a simple time series analysis, the relationship between outcome variable y_t and a set of K explanatory variables $\mathbf{X}_t = (x_{1t}, x_{2t}, \dots, x_{Kt})'$ is estimated through a simple ordinary least squares (OLS) regression model, shown in Equation (1) (Kripfganz & Schneider, 2023):

$$y_t = b_0 + b_1 t + \boldsymbol{X'}_t \boldsymbol{\theta} + e_t \qquad (1)$$

where b_0 is a constant, $b_1 t$ represents the slope of a linear time trend and e_t is the error term. This OLS regression can sometimes yield misleadingly large coefficient estimates, even when no actual relationship between the variables exists (Kripfganz & Schneider, 2023). This problem arises when the error term e_t is non-stationary due to non-stationarity of at least some of the variables in the model. Non-stationarity means that the statistical properties of the series, such as the mean and variance, change over time. Non-stationarity in the error term implies that the residuals are not randomly distributed but exhibit a systematic pattern over time. This systematic pattern can falsely inflate or deflate the size of the relationship between the dependent and independent variables, resulting in over- or underestimation of the coefficients. Therefore, stationarity of the error term is a key assumption of OLS regression.

To test for stationarity, I perform an Augmented Dickey-Fuller (ADF) and a Phillips-Perron (PP) test on all variables. The results of both tests show that all variables are non-stationary in their levels but become stationary after taking the first difference, indicating first-order integration (I(1)). An additional Kwiatkovski-Phillips-Schmidt-Shin (KPSS) test corroborates this finding. Based on this result, I chose an autoregressive distributed lag (ARDL) model for the purposes of this study. The ARDL is robust to problems arising from non-stationarity and does not require variables to be integrated in the same order, allowing the inclusion of variables that are integrated in order 1 (Adeleye et al., 2018; Belloumi, 2014). The ARDL model augments the simple OLS regression by including the lags of both the dependent and independent variables. The inclusion of lags aims at obtaining an error term free of serial correlation, thereby achieving its stationarity (Kripfganz & Schneider, 2023). Because the variables are non-stationary in their levels, I employed the Engle-Granger two-step procedure to test for cointegration among the variables. First, I estimated the long-run relationship using the ARDL model. Subsequently, I performed the ADF test on the residuals from this regression. The ADF test results indicated that the residuals were stationary, confirming the presence of a cointegrating relationship among the variables. Consequently, I proceed with the ARDL model in levels rather than first differences. An additional advantage of the ARDL model is its relative efficiency in the case of small and finite sample data sets (Adeleye et al., 2018; Belloumi, 2014), as in this study, providing further justification for the methodology.

The main identifying assumption is that any unobserved factors affecting the outcome variable are independent of whether the CCB is in place, conditional on a set of covariates (Mullally & Lusk, 2018), and so-called conditional independence given predictive proxies (CIPP) is obtained (White, 2006). This implies that when I account for certain key variables, the main variable of interest, our policy estimator, is not correlated to the outcome variable. Therefore, I can interpret the effect that contributed to the CCB as causal. Mullally and Lusk liken the CIPP to the time series equivalent of the conditional independence assumption (CIA) in cross-section and panel data settings. If CIPP holds, forecasting methods can be used for policy impact estimations (Mullally & Lusk, 2018; White, 2006).

The first step in this thesis is to estimate the CCB's impact on egg prices. Following Kripfganz and Schneider (2023), I use the following ARDL specification:

$$y_t = c_0 + c_1 t + \sum_{i=1}^{p} \phi_i y_{t-i} + \rho BCC_i + \sum_{i=0}^{q} \beta'_i \boldsymbol{X}_{t-i} + e_t \tag{2}$$

This is a general ARDL (p,q ..., q) model, with intercept c_0, linear trend $c_1 t$ and error term e_t. ϕ_i denotes the coefficients of the autoregressive component with lags p ∈ [1, p∗] and β'_i are the coefficients of a vector of independent variables **X** with lags q ∈ [0, q∗]. ρ is the estimate of our main variable of interest and represents the average impact of the CCB during the observed post-ban period.

The number of lags is optimised using the Bayesian Information Criterion (BIC). The BIC is a stricter criterion than the Akaike Information Criterion (AIC) and places a harsher penalty on model complexity. Hence, compared to the AIC, the BIC sacrifices some goodness of fit for model simplicity. Given the small sample size of the data, I prefer the BIC, as stricter criteria reduce the risk of overfitting the model.

After estimating the ban's impact, I apply forecasting techniques using the best specification of the ARDL, as established in the previous analysis. Based on data prior to the implementation of the ban, I constructed a forecast for the egg price. The forecast serves as a counterfactual to the actual, observed egg price. The forecast is based on the following ARDL specification:

$$y_t = c_0 + c_1 t + \sum_{i=1}^{p} \phi_i y_{t-i} + \sum_{i=0}^{q} \beta'_i \boldsymbol{X}_{t-i} + e_t \qquad (3)$$

Equation (3) is identical to Equation (2) except for the absence of the *ban* dummy. The dummy is not included, as the forecasting model does estimate the impact of the CCB but predicts the 'business as usual' scenario in the absence of a ban. Having constructed a counterfactual, I estimate a difference-in-difference model:

$$y_t = \beta_0 + \beta_1 treatment_i + \beta_2 postban_i + \beta_3 (treatment_i * postban_i) + e_i \qquad (2)$$

where y_t is the value of the dependent variable for observation *i. Treatment* is a binary variable indicating whether the observation is part of the treatment group (i.e., observed egg prices, subject to the CCB) or of the control group (i.e. the forecasted counterfactual). *Postban* captures any changes between the pre- and post-ban period that affect the control group and treatment group equally over time. β_3 is our coefficient of interest. It estimates the effect of the CCB on the treatment group, during the period when the CCB is implemented.
The forecasting method aims to reinforce the reliability of our previous estimates. Its primary purpose, however, is to research the temporal effects of the ban, allowing analysis of heterogeneous impact of time. Moreover, the forecasting method provides visual support for the analysis, which helps in illustrating trends and potential anomalies.

5. Results

5.1 ARDL Analysis of Egg Prices

The results of our main model specification, as specified by Equation 1, are presented in Table 2. Table 2 contains seven different model specifications that are increasing in complexity.

Model 1 is the most basic model specification, which estimates the price difference between the pre- and post-ban period, while only accounting for the time-series dynamics of egg prices. The estimated 8.5 percent post-ban price increase provides a first intuition of the CCB's impact. However, without the inclusion of control variables, this naïve estimate does clearly not satisfy the CIPP necessary for causal inference.

I extend the analysis by including a linear time trend variable and a dummy for when the fipronil scandal led to a strong increase in egg prices in Model 2. Accounting for the sudden and major market disruption in the observed data reduces the bias in the ban estimate. It enables the model to convert the temporary pre-ban price surge into an exogenous shock. In the absence of a fipronil dummy, I expect the impact estimate of the ban will be biased downward, as the price increase in the post-ban period will be comparatively smaller. The addition of the linear time trend aims to control underlying trends in the data beyond inflation, which itself has been accounted for by indexing all prices. In line with expectations, the ban coefficient in Model 2 increases to 16.7 percent. Interestingly, the CCB's price impact is estimated to be smaller than that of the fipronil scandal.

Model 3 further expands the analysis by including the major cost components of egg-laying farms. The post-ban period coincided with a large market disruption following the Russian invasion of Ukraine and the subsequent sanctions on the Russian economy by the EU, which led to a strong increase in energy and corn prices. Moreover, in this period characterized by high inflation, several increases in the minimum wage were passed. The inclusion of these variables partly explains the price increase during this period and aims to isolate the estimate of the ban's impact from wider market conditions. As a result, the ban estimate adjusts slightly downward to 14.5 percent, but it remains highly significant. Thus, the production cost variables explain part of the price increase that previously contributed to the policy change.

Model 3 expands the analysis by including a set of control variables to account for variations in laying farms' marginal production cost. During the post-ban period, European markets are characterized by instability and high inflation due to a post-covid recovery of the economy and the outbreak of the Russo-Ukrainian war. Consequently, the production inputs of laying farms are subject to large price fluctuations within that timeframe, which could potentially affect egg prices. Accounting for these price changes aims to isolate the CCB's impact from market volatility. The size of the resulting impact estimate is adjusted slightly downward by two percentage points, suggesting that part of the price increase previously contributed to the policy change is explained by changes in production costs.

Among all the control variables, an increase in labour costs has the largest impact on egg prices, with a 1 percent increase in minimum wages being associated with a more than 1 percent increase in egg prices. Diesel prices also show a significant positive price impact, whereas egg prices seem to be unaffected by the electricity price. Perhaps fixed long-term energy contracts have protected producers from fluctuating electricity prices. Alternatively, electricity costs may represent too low a proportion of the overall cost to have a significant effect on the ultimate egg price. Unexpectedly, there is a negative correlation between feed prices and egg prices. A potential explanation could be that high soy and corn prices induce a substitution effect, leading producers to switch to cheaper alternatives. An alternative explanation could be that the feed proxy was misconstrued. The composition of inputs for the feed proxy is based on an American study, which may not accurately reflect Germany's standard chicken feed.

As discussed in the data section, the production cost variables exhibit a similar pattern over time, which raises the concern of potential multicollinearity. When multicollinearity is present, the regression coefficients' standard errors are inflated, resulting in wider confidence intervals. As a result, coefficient estimates may be unstable, causing small changes in the model to yield widely varying estimates. Indeed, diesel and electricity prices are highly correlated ($r=0.91$), while both are highly correlated with feed prices ($r>0.84$). In this model specification, a variance inflation factor (VIF) test indicates a high risk of multicollinearity, with the diesel and feed variables scoring between 5 and 10, indicating potentially problematic collinearity, and the electricity variable exceeding 10, indicating serious multicollinearity issues. To address this concern, I have estimated the model without the electricity variable and diesel variable, respectively. This improved the VIF score without significantly changing the estimates. Secondly, I perform a principal component analysis (PCA), which is a statistical technique that integrates multiple colinear variables into a single variable. This too did not significantly change the model's estimates, confirming that high multicollinearity does not lead to instability in the model. Moreover, the independent variables are not highly correlated with the dependent variable (r<0.65). Based on these points, I conclude that multicollinearity does not jeopardize the reliability of the CCB's estimated impact.

Table 2: Results of ARDL analysis on egg price

Variable	(1) Egg Price	(2) Egg Price	(3) Egg Price	(4) Egg Price	(5) Egg Price	(6) Egg Price
Ban	0.085***	0.167***	0.145***	0.105**	0.122**	0.142***
	(0.0276)	(0.0352)	(0.0423)	(0.0502)	(0.0466)	(0.0387)
L1 Ln Egg Price	1.183***	1.003***	0.900***	0.900***	0.856***	0.858***
	(0.0912)	(0.0896)	(0.0930)	(0.0924)	(0.101)	(0.101)
L2 Ln Egg Price	-0.363***	-0.332***	-0.460***	-0.461***	-0.316***	-0.301***
	(0.0891)	(0.0804)	(0.127)	(0.127)	(0.0868)	(0.0845)
L3 Ln Egg Price			0.327**	0.337***		
			(0.124)	(0.124)		
L4 Ln Egg Price			-0.249***	-0.277***		
			(0.0776)	(0.0795)		
Ln Feed Price			-0.252***	-0.200**	-0.209**	-0.223***
			(0.0756)	(0.0830)	(0.0845)	(0.0826)
Ln Diesel Price			0.281**	0.279**	0.286***	0.285***
			(0.109)	(0.109)	(0.0996)	(0.0993)
Ln Electricity Price			-0.002	0.003	-0.001	-0.009
			(0.0291)	(0.0292)	(0.0314)	(0.0302)
Ln Minimum Wage			1.313***	0.903**	0.998***	1.187***
			(0.284)	(0.395)	(0.371)	(0.281)
Interest Rate				0.0279	0.014	
				(0.0188)	(0.0184)	
Fipronil		0.187***	0.206***	0.219***	0.200***	0.190***
		(0.0375)	(0.0350)	(0.0358)	(0.0375)	(0.0352)
Constant	Yes	Yes	Yes	Yes	Yes	Yes
Linear Time Trend	No	Yes	Yes	Yes	Yes	Yes
Month Fixed Effects	No	No	No	No	Yes	Yes
Observations	103	103	102	102	102	102
R-squared	0.892	0.914	0.938	0.940	0.957	0.957

The coefficients of the lags of egg prices exhibit a remarkable pattern, alternating between positive and negative values for each subsequent lag while decreasing in magnitude. This behaviour can be explained by market adjustment dynamics. Here, the response to a change in egg prices initially overshoots and then corrects itself over the subsequent periods. This process is similar but distinct from a reversion to the mean. In this scenario, egg prices tend to return to their long-run equilibrium path when deviations from it occur. Lastly, this pattern could indicate that the model overfits the data. This risk is especially apparent in combination with a high R-squared value. Overfitting occurs when the model becomes too complex, incorporating too many variables, leading it to capture noise in the data rather than underlying trends. The concern of overfitting will be addressed in Section 5.2, by validating the model's performance on out-of-sample data.

Model 4 adds an interest variable, representing both the cost of trade and the investment climate. In the agricultural economics literature, interest rates are frequently included to account for the broader economic environment. The inclusion reduces the CCB's estimated size to 10.5 percent. Lastly, Model 5 includes set-month dummies to account for any seasonal patterns in prices, which slightly increases our impact estimate.

The interest rate follows an atypical pattern. It remains largely flat, with a small linear decrease over time, until it suddenly soars in late 2022. The increase in interest rates was a response to high inflation, which was aimed at reducing aggregate demand. Thus, high price levels caused an increase in the interest rate, leading to a potential reverse causality. Therefore, I re-estimated the model without the interest variables, but accounting for seasonality, as shown in Model 6. The estimated 14.2 percent price increase is roughly equal to the estimate in Model 3, proving the earlier estimate is robust to seasonal effects.

The methodology assumes the non-stationarity of the error term, as this can lead to spurious estimates. I chose the ARDL model due to its ability to handle variables with first-order cointegration, which are individually non-stationary in their error terms. I conducted an ADF test on the residuals of the estimated models to test whether the model could handle the presence of a unit root in the variables. For each model specification, the null hypothesis of the presence of unit root is strongly rejected ($p<0.000$), indicating that the residuals of the model are stationary, which validates the choice of the ARDL model.

To further improve confidence in the reliability of the results, I conduct diagnostic tests for a serial correlation in the error term. Serial correlation is defined as the existence of a significant relationship between a variable and its lagged values, meaning that the current value of a variable has predictive power for future values. Thus, the presence of serial correlation in the error term implies a non-random distribution of the error term. This leads to a misleading inference about the coefficients, as the model's standard errors may be biased, which affects the p-value of the estimates. First, I performed a Breusch-Godfrey LM test, with which I found no evidence for serial correlation. To further confirm the absence of serial correlation, I conducted a Durbin-Watson test. The Durbin-Watson d-statistic ranges from 0 to 4, while a d-statistic of close to 2 indicates no serial correlation. The obtained d-stats for the estimated models were all within a 0.15 range of 2, with Model 7 obtaining a near-perfect d-stat of 2.001. Based on the results of the Durbin-Watson test in conjunction with the Breusch-Godfrey LM, I confidently reject serial correlation of the error term.

5.2 Forecasting Analysis of Egg Price

An ARDL predicts the value of y_t based on previous values of y_t and a set of current and lagged values of explanatory variables. To validate the predictive power of the ARDL model I use an out-of-sample forecasting method to estimate the impact of the ban. Additionally, this method provides visual support to statistical analysis.

I employ techniques to establish a counterfactual egg price. The counterfactual egg price serves as a control group against which observed egg prices are compared. I use a two-step approach. First, I establish the forecasting method's reliability by testing the forecast on a subsection of the data. Secondly, I proceed to forecast a post-ban counterfactual egg price.

The first step involves forecasting values for 2021, using data from 2015 up to and including 2020. The forecast is based on Model 7 of Table 1. This model was chosen because it has a lower mean absolute error (MAE), mean squared error (MSE), root mean squared error (RMSE), and mean absolute percentage error (MAPE) than the other model specifications. However, a Diebold-Mariano test does not indicate a significant ($p=0.363$) difference in forecasting accuracy between the models, meaning that other model specifications do not significantly underperform in forecasting accuracy compared to Model 7.

Theil's U statistic test is a commonly used metric to evaluate the accuracy of a forecasting model. It benchmarks the obtained forecast against a naïve baseline forecast, which assumes the value of the next period to be equal to the value of the current period. Theil's U statistic is calculated as the ratio of the RMSE of the forecast to the sum of the RMSE of the naive forecast and the root mean squared value of the forecast itself. A value smaller than 1 indicates the forecast model is more accurate than the naive benchmark, while a value greater than 1 indicates the forecast is less accurate than the naive benchmark. The closer Theil's U statistic is to 0, the better the forecast is compared to the naive model. In this analysis, the forecasted egg price model has a Theil's U statistic of 0.012. This value, being close to 0, highlights the model's effectiveness and reliability as a forecasting tool. A difference-in-difference shows no statistical difference ($p=0.148$) between the forecasted and observed values for the out-of-sample forecast, which further proves the ability of the forecast to correctly predict prices, thereby also taking away concerns of overfitting.

Table 3 Results of difference-in-difference analysis with estimated for different time periods.

	Actual		Forecast		Difference-in-
Post ban period	*Pre-ban mean*	*Post-ban mean*	*Pre-ban mean*	*Post-ban mean*	differences
Jan 2022 - Nov 2023	4.775	5.202	4.775	5.032	0.170***
	(0.021)	(0.041)	(0.021)	(0.0458)	(0.0671))
Jan 2022 - Sept 2022	4.775	5.011	4.775	4.777	0.233***
	(0.021)	(0.047)	(0.021)	(0.0126)	(0.0548)
Oct 2022 - Nov 2023	4.775	5.324	4.775	5.196	0.129***
	(0.021)	(0.0272)	(0.021)	(0.0224)	(0.0451)

For the second step, I run the chosen model on data from 2015 to and including 2021 to forecast the egg price for the period when the ban is effective. This forecast serves as a counterfactual 'business-as-usual' scenario under which no ban is in place. Graph 2 shows how the forecast compares to observed egg prices. From the graph, we can learn about the timing of the CCB's impact. Directly after the ban was implemented, actual egg prices strongly diverged from the forecasted counterfactual. After ten months, the difference between observed and forecasted prices decreases, and for some months there appears to be no significant price difference. To measure the timing of the effect, I perform the difference in difference analysis on three different post-ban periods: (1) for the complete dataset, (2) up until and including September 2022, and (3) from October 2023 onwards. Table 3 presents the estimates of the difference in difference analysis.

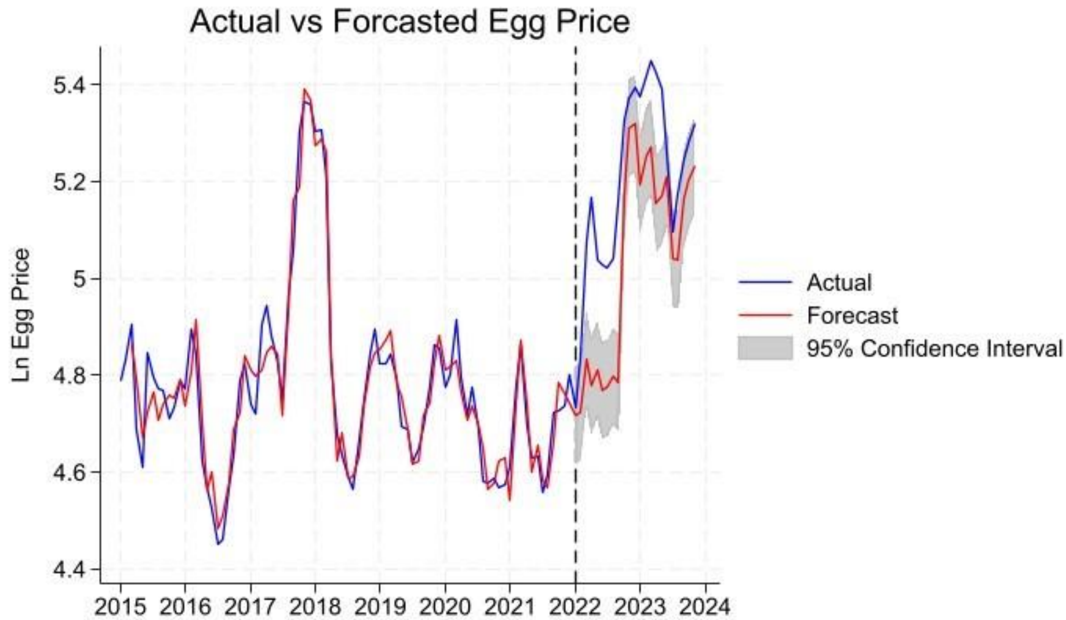


Figure 4: Forecasted counterfactual egg prices compared to observed egg prices, with a 95% confidence interval.

5.3 Impact Analysis of Poultry Farms

After establishing that the CCB leads to a significant increase in egg prices, the second part of the analysis shifts focus to understanding the impact on the egg supply. Investigating whether a reduction in supply or an increase in production costs drives the observed price increase is crucial to understanding the underlying market dynamics. Although it is beyond the scope of this thesis to discern the exact differential impact on consumers and producers, understanding changes in the supply side gives a first indication of the economic reasons behind the price increase and the distribution of social costs associated with the CCB.

For this analysis, I look at flock size, utilisation rate, yield, and egg production. Due to the increased costs of laying hens, poultry farmers may respond by reducing their flock size, leading to a lower utilization rate at their farms. The ex-ante estimation of the effect on yield is unclear. A fundamental change in production methods is not required, making significant yield changes unlikely. However, producers may be required to shift to a less productive dual-purpose breed. Therefore, a reduction in yield indicates the adoption of dual-purpose breeds, reducing the efficiency of operations. In contrast, an increase in yield suggests that the market drives out the least efficient farms, allowing more efficient farms to fill the void.

Poultry farms are categorised into seven categories based on the number of laying hens kept at the farm. I run an ARDL model for each size category separately, as well as the total. To further support these findings, I performed a fixed-effect panel data regression analysis with standard errors clustered at the farm size level.

The results are shown in Table 4. Using either the ARDL method (column 8) or fixed effects panel data regression (column 9), I observe no significant change in flock size, output, or efficiency for the industry as a whole. Columns 1 to 7 show the results differentiated by farm size level to test for potential heterogeneity effects between smaller and larger farms. Columns 3 and 6 reveal a weakly significant increase in output for medium- and larger-sized farms. However, based on the number of regressions run, we would expect 2 to 4 significant results (at a 5 or 10 percent significance respectively). Thus, these findings are consistent with the number of expected false positives at this significance level. However, two other unexpected findings warrant further analysis. For farms with 100,000 to 200,000 hens, a small yet highly significant increase in flock size is observed in column 6. For these farms, graphic analysis shows large, cyclical patterns in flock size, characterized by sudden increases and decreases in the number of hens kept. The ban's implementation date coincided with a sudden surge. Therefore, the significant finding is likely best explained as a statistical fluke. In column 2, a highly significant decrease in utilization rate is observed. A structural break in utilisation rate occurs, for which I have no explanation.

In conclusion, no significant changes to the industry occur on an aggregate level, nor is there significant heterogeneity between farms of different sizes. Thus, in line with expectations, no significant changes in the keeping of hens or the production of eggs were found.

Table 4 Results of industry indicators analysis, separated by company size

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Method	ARDL	ARDL	ARDL	ARDL	ARDL	ARDL	ARDL	ARDL	Panel Data
Company size	*0-5000*	*5,000-10,000*	*10,000-30,000*	*30,000-50,000*	*50,000-100,000*	*100,000-200,000*	*200,000+*	*Total*	*Total*
Ln_Flock Size	-0.001	-0.002	0.011	0.004	-0.012	0.036***	0.001	0.007	0.000
	(0.007)	(0.008)	(0.008)	(0.017)	(0.014)	(0.013)	(0.017)	(0.006)	(0.009)
Ln_Production	0.002	-0.014	0.019*	-0.001	-0.007	0.039*	-0.005	0.005	-0.006
	(0.020)	(0.013)	(0.011)	(0.016)	(0.020)	(0.021)	(0.026)	(0.011)	(0.009)
Utilisation	-0.724	-1.833***	0.303	0.156	1.248	0.524	1.557	0.068	-0.887
	(0.755)	(0.670)	(0.552)	(1.117)	(1.548)	(1.690)	(2.088)	(0.594)	(0.503)
Daily yield per	0.342	-1.086	1.556	-1.224	-0.441	-1.138	-0.859	-0.716	-0.827
100 hens	(1.266)	(0.876)	(0.948)	(1.375)	(1.319)	(1.307)	(1.592)	(0.773)	(0.322)

5.3 Robustness and Sensitivity Checks

In this section, I will conduct a series of robustness and sensitivity tests on our egg price analysis. These tests serve to validate the reliability and stability of the results, ensuring that the findings are not a statistical artifact created by the specific conditions of the research design.
Robustness tests can be broadly categorized into two types: those that test whether no significant results are found when they should not be found, and those that test whether significant findings hold when deviating from the original research design.

5.3.1 Placebo tests

First, I conduct a series of placebo tests to see whether the results are robust. I use the same model to calculate the impact of fictitious policy changes that begin at a different date than the CCB. The placebo policies should not yield significant results because there is no underlying change affecting egg prices. Finding significant results at random moments in time would cast doubt on our original findings, as they may also have been the results of randomness.

I tested seven different placebo policies. A placebo policy is estimated every 6 months in the period between the time that the effect of the fipronil crisis has fully dissipated and the implementation of the CCB. Table 5 reveals no significant results, indicating that the main findings of this thesis are not the result of a statistical artifact in the research design, strengthening the reliability of the results. The placebo tests indicated that the estimated effect of the CCB from January 2022 was not due to random fluctuations but rather represented a genuine change in the data~~,~~ attributable to the CCB.

Table 5: Results placebo test

Placebo Time	Estimate	Std. dev.
Juli 2018	-0.0233	(0.0401)
January 2019	-0.0095	(0.0327)
Juli 2019	0.0477	(0.0364)
January 2020	0.0305	(0.0362)
Juli 2020	-0.0089	(0.0386)
January 2021	-0.0440	(0.0457)
Juli 2021	0.0008	(0.0395)

5.3.2 Timing of the Impact

Based on the out-of-sample forecast analysis, we can conclude that the ban's impact was not uniform over time. Using different hypothetical starting dates, I tested the ARDL's sensitivity with respect to the timing of the CCB's start. I estimate the effect of the ban for each of the six months prior to the ban and eleven months after the ban. Table 6 shows that months before the implementation of the ban, egg prices started to significantly increase. This finding suggests an anticipation effect, where egg prices were raised in anticipation of the CCB. However, this explanation alone is unsatisfactory because no investments by poultry farms were required to adhere to the CCB, as poultry farms buy chicks from hatcheries. Instead, it is plausible that, when I include prior months, the robust post-ban price increase continues to yield significant results on average, despite no real price change in the months prior to the ban's implementation. The post-ban period consistently shows a significant price increase for the first 9 months, which reaffirms the previous findings. The robustness of the estimates with respect to timing suggests that the effect is attributable to the CCB.

Table 6: Results of Timing Sensitivity Analysis

Timing of the start of the CCB	Time relative to implementation of CCB	Impact CCB	Std. Dev.
Juli 2021	t-6	0.022	(0.0391)
August 2021	t-5	0.045	(0.0386)
September 2021	t-4	0.056	(0.0387)
October 2021	t-3	0.058	(0.0397)
November 2021	t-2	0.101***	(0.0383)
December 2021	t-1	0.130***	(0.0374)
January 2022	t = 0	0.142***	(0.0387)
February 2022	t+1	0.196***	(0.0385)
March 2022	t+2	0.227***	(0.0405)
April 2022	t+3	0.193***	(0.0430)
May 2022	t+4	0.134***	(0.0469)
June 2022	t+5	0.166***	(0.0466)
Juli 2022	t+6	0.173***	(0.0500)
August 2022	t+7	0.173***	(0.0500)
September 2022	t+8	0.145***	(0.0522)
October 2022	t+9	0.149***	(0.0539)
November 2022	t+10	0.127*	(0.0700)
December 2022	t+11	0.068	(0.0524)

5.3.3 Exogenous Shocks

One major challenge in this analysis is isolating the price impact of the CCB from macroeconomic shocks that occurred around the same period, especially following the Russian invasion of Ukraine on February 24, 2022, which was less than eight weeks after the ban's implementation. To control for subsequent sudden price increases, most notably energy, and crop prices, all relevant cost variables for poultry farms were included. However, unobserved factors associated with macroeconomic changes might still confound the original findings.

To address these concerns, I conducted a series of exogenous shock analyses. I ran the regression multiple times, each time including a dummy variable for only one exogenous shock. For each analysis, I included a dummy variable to account for a lasting exogenous shock, beginning in a specific month either six months before or eleven months after the CBB's implementation.

The results are presented in Table 7. Except for an exogenous shock in December, the estimates are robust to the inclusion of an exogenous shock in the months before the ban, with estimates remaining nearly equal to our initial finding of 14.2 percent. In December, the exogenous shock produced no significant results for either the CCB or the exogenous shock estimate. This is likely due to collinearity between the nearly identical exogenous shock dummy and the CCB variable, making the model unable to attribute the price increase to a single variable. Instead, the price increase is dispersed over two variables, resulting in an insignificant outcome for either variable.

Allowing for an exogenous shock in the first three months following the CCB implementation nullifies the ban's impact. There are two possible explanations: (i) the exogenous shock variable captures the CCB's delayed impact, or (ii) it captures the real effect of an exogenous shock. A delayed price impact is in line with expectations, as the cost increase associated with the CCB occurs when laying hens need to be replaced at the end of their productive life cycle. This replacement happens gradually, leading to a phasing-in of the CCB's impact. However, I cannot rule out the second explanation, as the timing of these exogenous shocks coincides with major macroeconomic shocks.

The end of February marks the beginning of the Russo-Ukrainian war and subsequent economic instability. In the following months, the EU imposed heavy sanctions on the Russian economy, which came at a significant cost to its own economy. The exogenous shock variables in February, March, and April, which coincide with these macroeconomic shocks, yield highly significant results and render the CCB's coefficients non-significant. Thus, the increase in egg prices, initially attributed to the CCB, now appears to be better explained by the impact of the Russo-Ukrainian war on the German economy. Exogenous shocks associated with new sanctions in June, July, and August also significantly affected egg price levels, leading to a small reduction in the size and significance of the initial CCB estimates.

From this analysis, we can draw an important conclusion regarding the CCB's impact on egg prices. The findings are robust to the inclusion of random exogenous shocks, but not to shocks associated with the Russo-Ukrainian war outbreak. A delayed impact of the CCB could explain this, but disentangling this effect from the war's impact proves impossible.

Table 7: Results of Sensitivity to an Exogenous Shock

Month of Exogenous Shock	Impact CCB on Egg Price	Std. Dev.	Impact Exogenous Shock on Egg Price	Std. Dev.
Juli 2021	0.145***	(0.0402)	-0.012	(0.0377)
August 2021	0.143***	(0.0416)	-0.002	(0.0388)
September 2021	0.146***	(0.0441)	-0.008	(0.0414)
October 2021	0.164***	(0.0482)	-0.036	(0.0463)
November 2021	0.137**	(0.0563)	0.006	(0.0538)
December 2021	0.096	(0.0735)	0.053	(0.0705)
-				
February 2022	-0.046	(0.0671)	0.237***	(0.0709)
March 2022	0.015	(0.0483)	0.215***	(0.0551)
April 2022	0.073*	(0.0438)	0.148***	(0.0503)
May 2022	0.114***	(0.0431)	0.074	(0.0507)
June 2022	0.102**	(0.0416)	0.115**	(0.0498)
Juli 2022	0.104**	(0.0414)	0.119**	(0.0530)
August 2022	0.104**	(0.0414)	0.119**	(0.0530)
September 2022	0.117***	(0.0412)	0.089	(0.0538)
October 2022	0.117***	(0.0413)	0.089	(0.0557)
November 2022	0.139***	(0.0447)	0.011	(0.0763)
December 2022	0.145***	(0.0429)	-0.009	(0.0543)

6. Discussion

Conservative estimates of the ban's impact on egg prices, on average, range between a 10 and 15 percent price increase. Given the 2022 supermarket price of €1.50 to €2.00 for a box of ten non-organic eggs, this results in a 1.5 to 3-cent cost increase per egg. This cost increase is comfortably within the range of the ex-ante reported willingness to pay for CFF eggs.

This study finds no significant effect of the CCB on egg production or flock size. This contrasts with the findings of Malone and Lusk (2016) and Mullally and Lusk (2018), who found a 35 percent decrease in both egg production and the number of laying hens following California's ban on battery cages. This difference highlights that a CCB is a relatively non-intrusive measure that does not require altering production methods. Investments to accommodate the CCB are only required from hatcheries, a very concentrated stage of the supply chain, which eases the transition.

Furthermore, the stability in egg production and flock size suggests that the CCB's economic impact is primarily reflected in price adjustments rather than changes in production. This implies that producers were able to pass on any cost increase to consumers without significantly affecting their business. This is consistent with the notion that egg prices are relatively price inelastic. Therefore, a tentative conclusion is that German egg consumers fully bear the social cost associated with the CCB.

Based on this assumption, we can make a quick back-of-the-envelope calculation of the loss in consumer surplus. Given Germany's egg revenue totaling €3.8 billion in 2022, the annual loss in consumer surplus is estimated to be €380 to €570 million in the first two years after the implementation of the ban. The results of this study indicate that, after an initial price increase, the ban's impact dissipates over time and may have fully disappeared after two years. Therefore, a rough initial estimate of the social cost of the ban amounts to a total of €750 million to €1 billion, or between €8.80 and €12 per capita.

Instead of inelasticity of demand, a positive demand shock provides an alternative explanation for increasing prices without a fall in production. Altruistic consumers now receive a superior product, increasing their willingness to pay, resulting in an upward shift in the demand curve. The new demand would accommodate the price increase without causing a decrease in consumption. The shift in the demand curve is associated with increased consumer surplus, which represents the welfare benefits that altruistic consumers derive from higher animal welfare standards. However, for this scenario to be true, not only must consumers be willing to pay more for CFF eggs, but they also need to be aware of the change in legislation. Since no study has measured public awareness of the CCB, I only have a rough indication of consumer knowledge. Although the Supreme Court's ruling prohibiting chick culling received some attention in news outlets, it did not make headlines. Most of the articles that can be found on the issue are published by animal welfare organizations rather than public news outlets. Google Trends reveals virtually no searches for *kükentöten* (chick culling), nor an increased interest at around the time of the court's ruling, suggesting a limited interest of the public in this issue. Therefore, a significant shift in the demand curve seems unplausible.

Despite this, it is important to recognize that the CCB not only comes at a social cost but also generates social benefits. Male chicks are arguably the primary beneficiaries of the CCB, and animal lovers may derive satisfaction from higher animal welfare standards. However, caution is required when accumulating benefits. Bergstrom (2006) warns of the potential for double-counting benefits when altruism is involved. In this context, counting both direct animal welfare benefits and indirect altruistic satisfaction from these benefits may inflate the perceived total benefit. Failure to properly account for double counting may lead to Kaldor-Hicks inefficiency, meaning that the gains of animals are insufficient to compensate for losses to humans (Lusk & Norwood, 2012). Lusk and Norwood (2012), therefore, argue that when evaluating the benefits of animal welfare policies, one should either (i) ignore human altruism in a non-speciesist analysis or (ii) include human altruism but ignore the benefits to animals. It is beyond the scope of this thesis to estimate and quantify welfare benefits accrued by animals; therefore, I limit this thesis to a brief discussion of the benefits to altruistic humans mentioned above.

Furthermore, the results of this thesis bolster the notion that we can implement animal welfare regulations without adversely affecting production levels. This may come as reassurance for the industry, indicating that animal welfare regulations can be implemented without jeopardizing their business model. When market mechanisms adequately compensate the industry for its production process adjustments, it may reduce its opposition to stricter regulation.

Despite the consistent and robust impact estimates found in this thesis, it is important to acknowledge its limitations. The primary challenge was isolating the CCB's price effect from other macroeconomic shocks, such as post-Covid inflation and especially the Russo-Ukrainian war. The findings proved sensitive to the inclusion of exogenous shocks shortly after the CCB's implementation, the timing of which coincided with the beginning of the Russo-Ukrainian war and the sanctioning of the Russian economy. This highlights the difficulty of using time series analysis to separate the impact of the CCB from other concurrent macroeconomic events. The occurrence of major macroeconomic shocks shortly after the CCB's implementation complicates an analysis of the impact over time. The findings of this study suggest that the price impact dissipates over time, which begs the question of the CCB's long-term impact. Although Mullally and Lusk (2018) successfully used time series analysis in a similar research setting, studying the impact of a battery cage ban on egg prices, this methodology proves limited during periods of economic instability. During such times, high volatility and unpredictability may introduce confounding variables that make it challenging to isolate the specific effects of the policy change. This may undermine the Conditional Independence given Predictive Proxies (CIPP) assumption underlying this study's methodology. Therefore, one should exercise caution in drawing conclusions from the findings of this study. While this study provides initial insights into the impact of the CCB, further research is needed to conclusively determine its effects.

Moreover, the apparent negative correlation between feed prices and egg prices warrants further investigation. It is an indicator of a potential misspecification of the model or a misconstruction of the feed price proxy variable. An exploration into the potential substitution effects and market conditions of chicken feed is necessary to understand the dynamics between feed and egg prices.

Given the initial insights and the limitations identified in this study, I will outline several avenues for further research. Firstly, a comparative study between countries with and without a CCB, where the economies of the countries involved are similarly impacted by macroeconomic shocks, could potentially better isolate the impact of the ban. As mentioned in the methodology section, this requires the mapping of trade between countries to account for potential spillover effects on the markets of control group countries.

Furthermore, using more detailed granular data instead of aggregate data could improve our findings and allow for a more reliable estimate of consumer surplus loss. For instance, Malone and Lusk (2016) using aggregate price data, initially found a loss in consumer surplus associated with California's battery cage ban ranging from $408 to $853 million per year. On the other hand, Mullally and Lusk (2018), using detailed scanner retail data, estimated a significantly lower loss in consumer surplus of only $25 million per year, demonstrating the earlier estimate to be off by a margin of 16 to 35 times. This example underscores the importance of using detailed data.

Although this thesis briefly addressed poultry industry outcomes, it was beyond the scope and means of this study to provide a rigorous impact analysis of industry effects. To further understand the distribution of economic costs associated with the ban, a more in-depth analysis of the poultry industry is required. Future research should explore the potential heterogeneity of impacts between farms and across various stages of the supply chain.

Germany's case was unique in that it was the first country to outlaw routine chick culling and transition to culling-free egg production. Germany implemented the ban at a time when the primary alternative, in-ovo sexing, was not yet available for large-scale commercial use. The ban proved a catalyst for technological developments. According to Innovate Animal Ag (2024), the capacity for in-ovo sexing increased by 60 percent in 2023 alone. Consequently, as of September 2023, 15 percent of the total population in the EU were in-ovo sexed. The effect of increasing capacity of in-ovo sexing may be visible in the results of this study, as this research shows that the CCB's impact on egg prices diminishes over time. Therefore, the findings of this study form an upper bound of the cost expected for other countries contemplating implementing a ban. Because Germany was the first to implement a ban, it has borne a disproportionate amount of the transition costs.

7. Conclusion

Against a backdrop of plausible introductions of chick culling bans (CCBs) in European countries and the EU, this thesis sets out to examine the economic impact of such bans on egg prices and egg production. This thesis exploited Germany's pioneering 2022 CCB as a case study. To date, Germany is still the only country to enforce a CCB.

Using ARDL time-series analysis and forecasting techniques, this thesis finds an average 10 to 15 percent price increase, equivalent to an additional 1.5 to 3 euro cents per egg. This cost increase is well within the range of the reported willingness to pay for CFF eggs before the ban's implementation. The estimate is also compatible with an expected 1 cent increase in production costs per egg due to in-ovo sexing. Notably, the price impact is felt most pronounced directly following the implementation of the ban, and it almost fully dissipates after two years. This can be attributed to in-ovo sexing technologies' upscaling and cost reduction.

At the same time, this study finds no significant disruption in egg production or laying hen flock size. Market adjustments have primarily occurred through prices. This suggests that producers have been able to pass the additional costs on to consumers without disrupting supply. Consequently, industry might endorse stricter animal welfare regulations that do not negatively impact business operations upon observing that stricter animal welfare regulations do not negatively impact their business operations and profit margins.

A back-of-the-envelope calculation estimates a total loss of consumer surplus between €750 million and €1 billion over two years. By the end of the observed two years, there were hardly any significant price increases. Therefore, the social cost could remain limited to this estimate, and not further increase in the following years.

These findings contribute to understanding the economic feasibility of animal welfare regulation. It demonstrates that implementing such measures can be relatively non-disruptive. Producers have successfully offset their cost increase by raising consumer prices, suggesting that implementing a CCB does not necessarily compromise market stability.

For policymakers, the results highlight the potential for passing similar legislation in other countries without causing severe economic shocks. This study shows that the transition towards chick-culling-free egg production can take place without any significant disruptions to production. The estimates of this study likely present an upper bound to the cost, as the lack of widespread availability of in-ovo sexing technology was a major hurdle in the transition towards culling-free production. Technological advancements and commercial adaptations of this technology have since removed this obstacle, making it cheaper to transition.

Further research should continue to explore in more detail the specific factors leading to a cost increase and the long-term economic impacts of various animal welfare regulations across different contexts. Further enhancing our understanding of the impact of animal welfare regulations is necessary for informed decision-making, balancing economic feasibility with ethical considerations and societal preferences, to ensure both animal welfare and economic continuity.

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