

Juarez-Torres, Miriam; Arellano-González, Jesús; Contreras-Astiazaran, Benjamin

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## The effect of avian influenza outbreaks on table-egg prices: Evidence from the Mexican market

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Miriam Juárez-Torres  
Banco de México

Jesús Arellano-González  
Banco de México

Benjamín Contreras-Astiazarán  
Banco de México

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## The effect of avian influenza outbreaks on table-egg prices: evidence from the Mexican market\*

Miriam Juárez-Torres<sup>†</sup>  
Banco de México

Jesús Arellano-González<sup>‡</sup>  
Banco de México

Benjamín Contreras-Astiazarán<sup>§</sup>  
Banco de México

**Abstract:** This paper investigates the effect of Highly Pathogenic Avian Influenza (HPAI) outbreaks on table-egg prices in Mexico. The analysis relies on monthly panel data of the price index of table eggs at the city level linked to records of HPAI outbreaks occurred in producing municipalities. Our findings suggest that exposure to an average HPAI outbreak immediately increases the price of table eggs by 1.5% relative to the price that would be observed in a scenario without HPAI. Exposure to HPAI outbreaks also has lagged effects. The highest increase (4.8%) is observed two months after the outbreak. Afterwards, the effect decreases and vanishes by the seventh month. Our results also suggest that the impact of HPAI outbreaks on the price of table eggs has decreased over time mainly due to a lower frequency and intensity of HPAI outbreaks possibly associated with an increased efficiency of the protocols of prevention, surveillance, control and eradication of HPAI outbreaks.

**Keywords:** egg prices, panel data, local markets, Avian influenza

**JEL Classification:** Q11, Q12, Q13, Q18, I18

**Resumen:** Este trabajo investiga el efecto de los brotes de influenza aviar altamente patógena (IAAP) en los precios del huevo en México. El análisis se basa en datos en panel mensuales del índice de precios del huevo a nivel de ciudad vinculados con registros de brotes de IAAP ocurridos en municipios productores. Nuestros hallazgos sugieren que la exposición a un brote promedio de IAAP aumenta inmediatamente el precio del huevo en 1.5% en relación con el precio que se observaría en un escenario sin IAAP. La exposición a brotes de IAAP también tiene efectos rezagados. El mayor aumento (4.8%) se observa dos meses después del brote. Posteriormente, el efecto disminuye y desaparece en el séptimo mes. Nuestros resultados también sugieren que el impacto de los brotes de IAAP en el precio del huevo ha disminuido con el tiempo debido principalmente a una menor frecuencia e intensidad de los brotes de IAAP, posiblemente asociada con una mayor eficiencia de los protocolos de prevención, vigilancia, control y erradicación de brotes de IAAP.

**Palabras Clave:** influenza aviar, precios del huevo, datos panel, mercados locales

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<sup>†</sup> Dirección General de Sistemas de Pagos e Infraestructuras de Mercados. Email: mjuarez@banxico.org.mx

<sup>‡</sup> Dirección General de Investigación Económica. Email: jesus.arellano@banxico.org.mx

<sup>§</sup> Dirección General de Investigación Económica. Email: bcontrerasa@banxico.org.mx

## **1. Introduction**

The Highly Pathogenic Avian Influenza (HPAI) virus has the potential to inflict significant economic losses to the table-egg industry because its eradication typically requires the slaughtering of sick and exposed birds to prevent the spread of the virus across producing areas. Its detection also activates mobility restrictions to geographically contain its spread further reducing the availability of table eggs in the market. As a result, HPAI outbreaks (defined as the widespread incidence of a highly contagious and deadly strain of HPAI) are typically associated with a contraction of the supply of table eggs and higher table-egg prices. The effect of HPAI outbreaks could be magnified if table egg production is geographically concentrated because when an HPAI outbreak hits an important producing area, a high share of production is at risk and prices could increase due to reduced expectations about the current and future availability of table eggs in the domestic market.

In this article, we estimate the effect of HPAI outbreaks on table-egg prices in Mexico, a country where most of the supply of table eggs is domestic with a small participation of imports in domestic consumption. Consequently, the domestic availability of table eggs is highly influenced by supply shocks experienced domestically. Table-egg production in Mexico is also highly concentrated since only two out of 32 states (Jalisco and Puebla) jointly account for more than 70% of total annual production. HPAI outbreaks affecting these high-producing areas could severely reduce the supply of table eggs to the whole Mexican domestic market.

For the estimation, we rely on panel data of the price index of table eggs at the city level obtained from the National Institute of Statistics and Geography (INEGI, by its Spanish acronym), the institution in charge of officially quoting the Consumer Price Index (CPI). We also utilize monthly records of HPAI outbreaks in producing areas at the municipality level obtained from the National Food Safety and Quality Service (SENASICA by its Spanish acronym), the phytozoosanitary authority of the country. The time period covered in our analysis goes from January 2011 to December 2022. We link the occurrence of HPAI outbreaks with prices observed in each city using mobilization records between Mexican

municipalities provided by SENASICA. These records are gathered by SENASICA as part of its phytozoosanitary regulations regarding the movement of agricultural products across Mexico. This information allows us to infer the distribution routes of table eggs between municipalities and associate episodes of HPAI in producing municipalities with table-egg prices observed in the cities they supply.

With this information, we estimate fixed effects regressions with two approaches. We first estimate an *exposure effect* using a categorical variable that links the occurrence of HPAI outbreaks in producing municipalities with the cities served by such producing areas. We also estimate an *intensity effect* in which the categorical variable is replaced by a continuous variable enumerating the number of slaughtered birds in producing municipalities. We control for monthly lagged effects by including up to 7 lags of the explanatory variables which allows us to assess the duration of the effect within a time window of 8 months. This period is slightly longer than the amount of time required to repopulate the flock of laying hens in production. Typically, laying hens start to produce table eggs at the age of 5-6 months (FAO, 2003). The regression also includes city, year and month fixed effects.

The results suggest that *exposure* to HPAI outbreaks immediately increases the price of table eggs by 1.5% relative to the price that would be observed in a scenario without the disease. Exposure to HPAI outbreaks may also have persistent lagged impacts on table-egg prices up to 6 months after their initial detection. These lagged effects are at first increasing and reach a maximum of 4.8% two months later. The effects are positive but decreasing afterwards. By the sixth month, the price of table-egg is 1.3% up relative to the price that would be observed in a scenario without the disease. By the seventh month, the effect vanishes. Estimates of the *intensity effect* are, in general, in line with the dynamic suggested by the *exposure effect* and suggest a positive elasticity of table-egg prices with respect to the number of slaughtered birds during HPAI episodes. We estimate that, within the sample period, HPAI outbreaks may have increased the price of table eggs by as much as 15.0%, on average, at the national level. Price increases were particularly high between 2012 and 2016 and are associated with the numerous outbreaks that affected the main producing state in that period. After 2016, the impact of table-egg prices decreased due to a lower frequency and intensity of HPAI

outbreaks and less affectations in the main producing areas. This reduction could also be partially due to improved and more effective policies of prevention, control, surveillance, and eradication of HPAI outbreaks enforced and promoted by SENASICA in this period.

The contribution of this paper is twofold. First and foremost, we expand the literature that documents the impact of HPAI outbreaks on economic outcomes in the context of a developing country. Most of the existing literature focuses on the USA (Ramos et al., 2017). Because of its role as a major exporter of poultry products, several studies investigate the effect of exports restrictions on the US poultry industry (Cakir et al., 2018; Thompson, 2018; Thompson et al., 2020; MacLachlan et al., 2022). Other studies estimate the effect of HPAI outbreaks on business profitability and poultry prices in the USA. For example, Paukett et al. (2018) conclude that US wholesalers increased their revenues during the 2014-2015 HPAI outbreak mainly because they were able to pass down the burden of higher costs to retailers and final consumers in the form of higher prices and because the costs of handling the outbreak (bird depopulation) was entirely borne by producers. Huang et al. (2016) investigate table-egg price formation across US regions outbreaks and conclude that, as a result of the 2014-2015 HPAI outbreak, the Southeast, an important producing region, emerged as another major source of price formation having a greater price influence in other regions. The analysis of HPAI outbreaks and its effects on economic outcomes in a developing country setting is basically nonexistent. This paper provides important evidence regarding the causal effect of HPAI outbreaks on table-egg prices in the context of a developing country with a high risk of exposure given its high concentration of table-egg production in a few areas. The results of this paper could serve as a reference for other developing countries with similar challenges.

Second, in contrast to the existing literature, this article utilizes panel data. Existing studies mostly rely on partial equilibrium models, gravity models of trade (Cakir et al., 2018; Thompson, 2018; Thompson et al., 2020) or time series techniques (MacLachlan et al., 2022; Paukett et al., 2018; Huang et al., 2016) applied to aggregated data. The estimation in this article relies on spatial and time variation of table-egg prices and HPAI outbreaks. Our price series vary at the city level while our indicator of HPAI outbreaks is constructed using information from producing municipalities that may or may not be nearby the cities. Our

analysis considers all the markets in the country and their commercialization links to producing areas. By taking into account these linkages, we are able to estimate the effect that HPAI outbreaks have on table-egg prices in markets located across subnational boundaries and not necessarily in or near to the producing areas. HPAI outbreaks affect local production and prices first. Then, the effect of a reduced production and of further mobility restrictions to limit the spread of the outbreak gets transmitted to other markets according to existing commercialization networks. The effect on final consumption markets will depend on whether the affected area is a major supplier of table eggs for those markets. The use of panel data allows us to exploit this local variation and estimate the causal effect of HPAI outbreaks on table-egg prices with more precision.

The findings of this paper are relevant to the Mexican context because table eggs constitute an important source of protein for consumers and are a major component of the Mexican diet. Mexico's per capita consumption of table eggs is about 24 kg, which is the highest in the world (OECD/FAO, 2023; UNA, 2022). Mexican households devote about 3.5% percent of their total food expenditure to the purchase of table eggs (Garza-Montoya et al., 2017). Thus, price increases resulting from HPAI outbreaks may have important household welfare consequences, particularly for low-income households as they are more likely to devote a larger share of their expenditures to egg consumption. Table eggs are the cheapest form of animal protein consumption, thus, in the face of a price increase, low-income households are less likely to replace egg consumption with other forms of animal protein such as beef, pork or chicken.

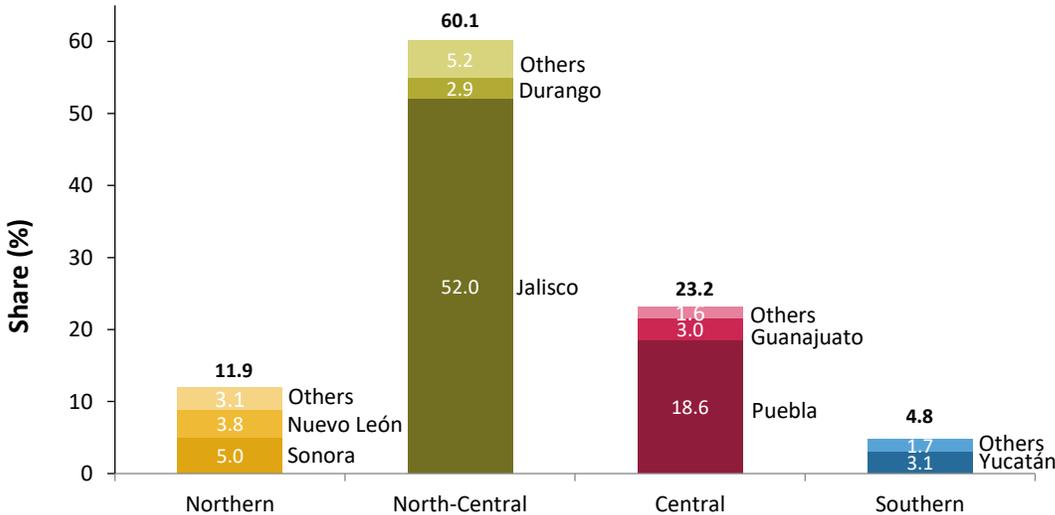
## **2. The context of table-egg production in Mexico**

In 2022, Mexico's table-egg production reached 3.1 million of metric tons (mt), a 1.8% increase with respect to the previous year and the highest level of production achieved historically (see Figure A1 in the Appendix). With these numbers, Mexico became the sixth largest producer of table eggs in the world accounting for 3.7% of global production (SADER-SIAP, 2023). In terms of table eggs, Mexico is practically a self-sufficient country. Between 2011 and 2022, imports and exports represented less than 1% of Mexico's domestic

supply and demand, respectively (see Figure A1). As most of the domestic supply of table eggs is produced domestically, prices are highly susceptible to the influence of domestic supply shocks.

The production of table eggs in Mexico is characterized by a high geographical concentration. 60.1% of the national production is generated in one single region, the North-Central (see Figure 1), followed by the Central region with an additional 23.2%.<sup>1</sup> At the state level, more than 70% of the national production is generated by two states, Jalisco and Puebla. At the municipality level, about 54% of the national production of table eggs is concentrated in only 10 municipalities, 7 of them located in the state of Jalisco. Throughout the year, the contribution of the main producing states, Jalisco and Puebla, remains relatively constant and accounts for about 70.0% of the total supply of table eggs each month (see Figure A3 in the Appendix).

**Figure 1. Average distribution of table-egg production by state and region**



Source: Own elaboration using annual production data from SIAP for the period 2006-2022.

The geographical concentration of table-egg production in Mexico, exacerbates the vulnerability of production and prices to the occurrence of supply shocks affecting the industry. In particular, it makes the Mexican table-egg industry highly vulnerable to the

<sup>1</sup> The regional distribution of the 32 states of Mexico can be seen in Figure A2 (in the appendix) and adheres to regionalization adopted in the Regional Economic Report of Banco de México.

negative consequences of HPAI outbreaks affecting the main producing areas because a large share of production will be at risk of being lost and because the mobility restrictions to contain the outbreak will further limit the availability of table eggs in the market. Mexico's domestic consumption of table eggs basically depends on the stability of the production of Jalisco and Puebla. HPAI outbreaks affecting these states could interrupt this stability and create upward pressures in table-egg prices.

### **3. A brief recount of HPAI outbreaks in Mexico**

Figure 2 presents a timeline of HPAI outbreaks in Mexico. The first outbreak dates back to late 1993 when a low pathogenic H5N2 virus was detected in commercial poultry farms in central Mexico. The virus had mutated to high pathogenicity in 1994 and spread to several states in 1995, including Jalisco and Puebla. (SAGAR, 1997). The highly pathogenic H5N2 virus was last isolated in May 1995 and eradicated in June 1995. This outbreak caused economic losses of 49 million dollars considering the cost of the emergency program, the value of poultry lost, and the purchase of vaccines (Villareal, 2009). While the highly pathogenic H5N2 has been eradicated, the low pathogenic version of this virus has continued to circulate in domestic poultry populations in Mexico (Lee et al., 2004; Xu et al., 2022).

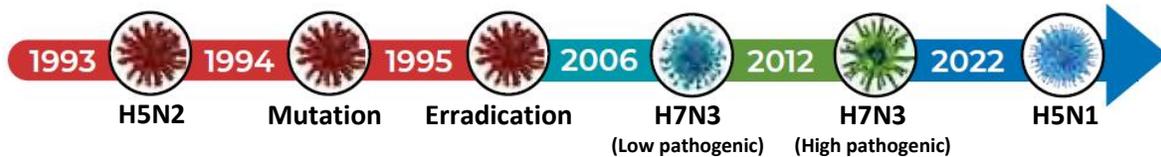
No major outbreaks affected poultry production in Mexico until June 2012, when a highly pathogenic H7N3 virus was detected in two major producing municipalities of Jalisco.<sup>2</sup> The virus quickly spread to neighboring producing areas in spite of the establishment of quarantine areas (FAO, 2012). After the implementation of a vaccination program and several other biosecurity measures, the virus reduced was last detected in August 2012. This outbreak caused a loss of 22.3 million birds in 2012 which represented about 18.6% of the total bird inventory of Jalisco. The vast majority of affected birds were laying hens (DINESA (1), 2022; SADER-SENASICA, 2022). The 2012 H7N3 outbreaks have been the deadliest in the history of HPAI in Mexico. The H7N3 virus reemerged in January 2013 after being

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<sup>2</sup> At first, it was thought that the low pathogenic H7N3 virus found in 2006 had developed into a highly pathogenic subtype. Later tests confirmed that the two viruses were in fact quite different and that the 2012 virus was a new subtype. The 2006 virus was used as the seed virus to produce the vaccine that would prove extremely helpful in the management of the 2012-2013 H7N3 outbreaks (Wright, 2012).

detected in a commercial poultry farm in the state of Aguascalientes. During 2013, new cases were again detected in Jalisco, Puebla, Guanajuato and Querétaro. Since then, the H7N3 virus has spread to a total of 18 states. In Jalisco, the largest table-egg producer, H7N3 outbreaks have been detected almost on yearly basis (Navarro-Lopez et al., 2022; SENASICA, 2024).

**Figure 2. Timeline of highly pathogenic avian influenza outbreaks in Mexico**



Source: SADER-SIAP (2023).

In early October 2022, the highly pathogenic H5N1 virus was detected for the first time in a wild bird in Mexico (DINESA (5), 2022). In the following weeks, several other cases were identified across Mexico. Because of its high lethality, the appearance of the H5N1 virus in Mexico was a cause of great concern in the Mexican poultry industry.<sup>3</sup> In late October, the virus was detected in a commercial table-egg farm in the northern state of Nuevo León. Additional cases were later detected in commercial poultry in Jalisco, Sonora, and Yucatán. Between October and December 2022, a total of 23 positive cases were detected in commercial poultry farms and more than 5 million birds either died or were slaughtered as a result of the diseases (DINESA (7), 2023). The last positive cases of the H5N1 virus were detected in late march 2023 in wild birds in Jalisco. At this point, the virus was present in 13 Mexican states. Overall, between October 2022 and March 2023, 56 H5N1 outbreaks were identified and a total 6.8 million birds were affected (DINESA (12), 2023).

In Mexico, poultry producers are legally required to report any suspicious case of avian influenza to SENASICA (DOF, 2018). Once notified, SENASICA makes a diagnosis and deploys all the protocols of surveillance and control to prevent the spread of the disease to neighboring areas, including the slaughter of sick and exposed birds in affected farms. If SENASICA considers that the outbreak poses a high enough risk to the stability of table-egg

<sup>3</sup> By the end of 2022, this virus had affected 53.1 million poultry in the United States. This disease still continues decimating poultry production in that country.

production, the National Animal Health Emergency Device (DINESA, by its Spanish acronym) is activated.<sup>4</sup> SENASICA coordinates DINESA with state governments and the poultry industry. Producers, intermediaries, retailers and all those persons who carry out activities related to the production, industrialization, transport and commercialization of birds, their products or by-products are obliged to comply with DINESA (DOF, 2023b).<sup>5</sup> Once DINESA is activated, the slaughter of birds and the restrictions to the mobilization of poultry products across the Mexican territory become fundamental to prevent the spread of HPAI.<sup>6</sup> The federal government assumes the costs of implementing DINESA and of depopulating affected farms (DOF, 2007) but the cost of lost production is entirely borne by the producers (Villareal, 2009).

HPAI outbreaks have immediate effects on table-egg production and market availability. With the slaughter of laying hens, production decreases and the mobility restrictions to poultry products put in place to prevent the spread of the virus further reduces the availability of table eggs in the market. The timing of the outbreak within the production cycle of the farm is also important. Laying hens could have up to two cycles of production, the first with an approximate duration of 12 months and a second one with a duration of up to 6 months

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<sup>4</sup> As a result of avian influenza outbreaks, DINESA has been activated 5 times. The first time was on January 1995 because of the H5N2 outbreaks (SAGAR, 1997). The second and third times occurred in June 2012 and June 2022 as a response to the H7N3 outbreaks (DOF, 2012a; DOF, 2022). Finally, DINESA was activated for a fourth and fifth time on January and December 2023 to address the zoo sanitary emergency caused by the H5N1 virus (DOF, 2023a; DOF, 2023b).

<sup>5</sup> DINESA is based on four basic principles: *surveillance*, *diagnosis*, *control*, and *education and promotion*. Surveillance includes all the epidemiological research activities such as the identification of potential positive cases and the tracking and sampling of affected birds. The diagnosis involves the analysis of the samples taken in high-security laboratories officially designated by SENASICA. Control activities refer to the slaughter of sick and exposed birds, the sanitization of contaminated farms, the use of sentinel birds to monitor the presence of the virus in affected farms, and the establishment of quarantine zones. Finally, education and promotion include activities such as the training of the personnel that participate in DINESA, meetings with poultry producers to communicate particular details about ongoing HPAI outbreaks, and the use of print and digital media to let the general public know the evolution of the zoo sanitary emergency and the different actions implemented by SENASICA to control it (SAGAR, 1997).

<sup>6</sup>With DINESA, the free transit of birds and poultry products from affected areas to disease-free areas is restricted. The movement of products is restricted too because they could also carry the virus with them. In the particular case of table eggs, the HPAI virus could be present on their shells if laid by an infected hen. Non-infected eggs could also get contaminated if collected, handled or packaged in an infected environment. Farms within quarantined zones need an HPAI-free certificate issued by SENASICA if they want to move their products out of the quarantined area (DOF, 2011; DINESA (7), 2023). The DINESA protocol defines the criteria for the establishment of such quarantine areas (SADER-SENASICA, 2012).

after a two-month break to renovate plumage and regenerate their reproductive system (Castillo Villanueva et al., 2017; SIAP, 2024). It is up to the farmer to decide whether or not to extend the life of the bird to two cycles, depending factors such as layer quality, production costs, and market conditions (price of table eggs). When a HPAI outbreak is detected in a farm whose layers are in their first cycle, the flock must be slaughtered without the possibility of continuing to a second cycle. So, HPAI outbreaks also decrease future production in farms that at the time of the outbreak were in their first cycle.

As previously mentioned, table-egg imports represent a small share of Mexico's domestic demand. However, severe HPAI outbreaks are typically followed by important increases in table-egg imports. For example, in 2012, the value of table-egg imports increased by 46% compared to 2011, as a result of the H7N3 outbreaks that severely decimated table-egg production that year (González, 2013). To facilitate imports, the Mexican government typically eliminates tariffs on specified quotas of imported eggs (DOF, 2012b; DOF, 2012c). If done promptly, the facilitation of imports may ensure a continued supply of poultry products, maintain food security and alleviate the upward pressures in prices that HPAI outbreaks create.

## **4. Data**

### **4.1 Outbreaks data**

Records of HPAI outbreaks in commercial poultry were obtained directly from SENASICA's General Directorate of Operations. The data covers the period from January 2012 to December 2022 and identifies the date of the outbreak, the virus subtype, the location of the affected farms and the total number of affected birds. Between 2012 and 2022, there were a total of 343 HPAI outbreaks detected in commercial poultry farms. Figure 3 displays their monthly evolution and distribution per state (panel a) and the bird losses caused by these outbreaks as a percentage of the national flock (panel b). The outbreaks started in 2012 in Jalisco, the major producer of table eggs in the country. Between June and August 2012,

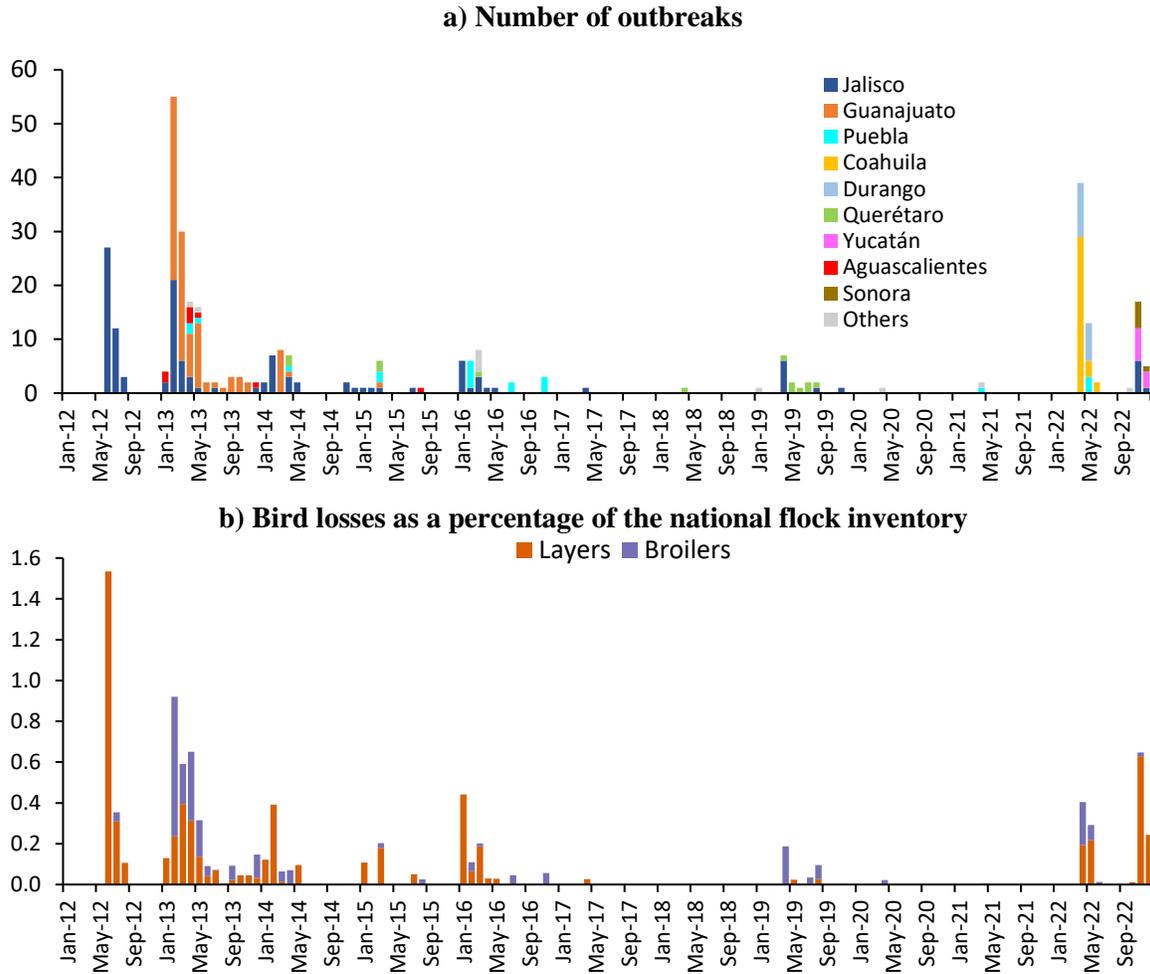
Jalisco was hit with a total of 42 H7N3 outbreaks.<sup>7</sup> In 2013, the virus spread to the neighboring states of Guanajuato and Aguascalientes and to the (not adjacent) state of Puebla, the second largest producer of table eggs in the country. That year, a total of 137 outbreaks were registered. Between 2014 and 2016, H7N3 outbreaks continued to affect the major state producers of Jalisco and Puebla, but the total number of outbreaks decreased considerably. Numerous H7N3 outbreaks re-emerged in 2019 affecting mostly the states of Jalisco and Queretaro. Finally, in 2022, a total of 77 HPAI outbreaks affected the country. These included 54 outbreaks of the H7N3 type that occurred between May and June, affecting mostly the northern states of Coahuila and Durango, and 22 outbreaks of the novel H5N1 virus which was detected in a commercial poultry farm of Nuevo León in October 2022. In the following months, additional outbreaks of this virus were identified in Sonora, Jalisco and Yucatán. Most of the outbreaks concentrated in Sonora and Yucatán, states with low market shares and patterns of commercialization confined to few neighboring states.

In terms of bird losses, panel b) in Figure 3 shows that the highest loss was recorded in June 2012 when about 1.5% of the national flock was slaughtered because of HPAI outbreaks. These bird losses were mostly concentrated on layer farms in Jalisco. Slaughters were uninterrupted during 2013 and part of 2014 affecting both, layer and broiler farms. Between 2014 and 2022, slaughters associated with HPAI outbreaks were scattered and small relative to the size of the national flock. More recently, in October 2022, the slaughters associated with the novel AH5N1 represented about 0.7% of the national flock.

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<sup>7</sup> These outbreaks were concentrated in 6 municipalities that together represent about 25% of the total production of table eggs in Mexico: Tepatitlán de Morelos (14.8%), Acatic (6.6%), Jalostotitlán (1.7%), Valle de Guadalupe (1.5%), San Ignacio Cerro Gordo (0.3%) and San Miguel el Alto (0.01%).

**Figure 3. HPAI outbreaks in Mexico between 2012 and 2022.**



Source: Own elaboration using information from SENASICA.

## 4.2 Table-egg prices

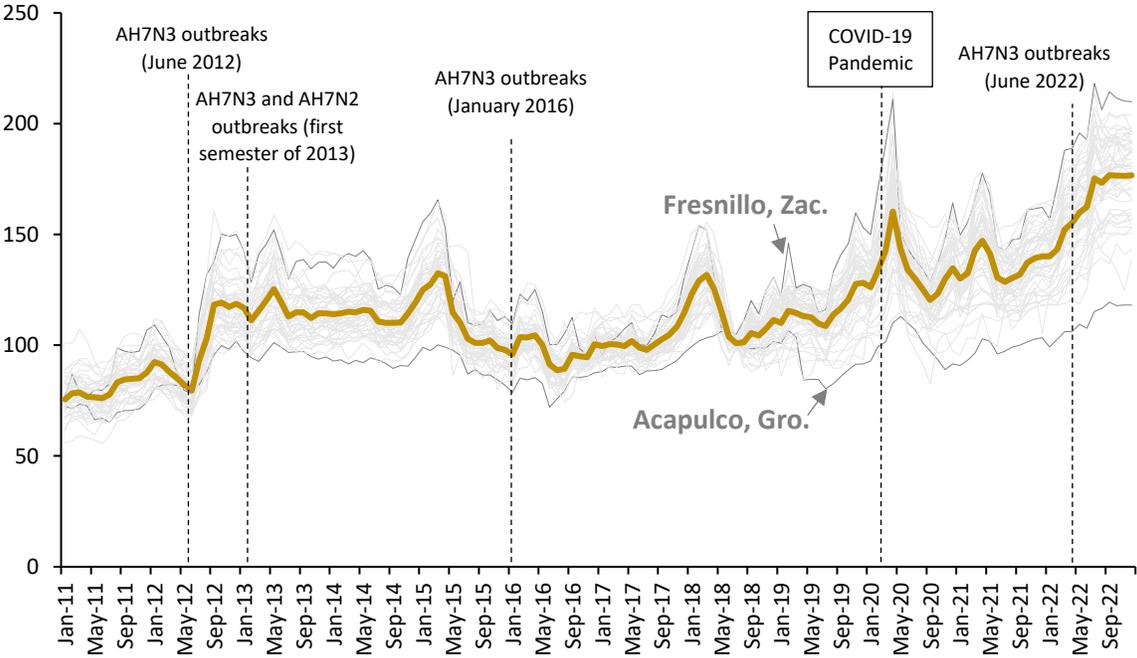
Table-egg price index series were obtained from INEGI. Our sample comprises the 55 cities where INEGI quotes the CPI and covers the period from January 2011 to December 2022.<sup>8,9</sup> Figure 4 displays the evolution of table-egg prices during the sample period. The brown thick line refers to the national average while the gray thin lines represent the price index series in

<sup>8</sup> INEGI is the federal institution in charge of calculating and publishing the CPI. For this process, INEGI quotes the price of several good and services that grouped in 299 different items in 55 representative cities across Mexico. CPI cities comprehend large metropolitan areas as well as small urban localities. On July 2018, INEGI updated its methodology to calculate the CPI. As part of this update, INEGI increased the number of cities from 46 to 55 (INEGI, 2018). In our sample, the 9 new cities do not have information before August 2018.

<sup>9</sup> Figure A4 (in the Appendix) displays the location of the 55 cities included in the sample.

each of the 55 cities in our sample. During the sample period, the average price of table eggs increased considerably, by 133.9%. Some episodes of price increases seem to coincide with the onset of HPAI outbreaks which are identified by vertical lines. For example, there is a huge spike in table-egg prices right after the June 2012 outbreaks, which were the first in decades. There is also a spike in table-egg prices right around the beginning of the COVID-19 pandemic although an increasing trend is visible since the beginning of 2020. The price index of table eggs varies substantially at the city level. For example, in December 2022, the table-egg price index in the city of Fresnillo, Zac. (in the North-Central region) was 77.6% larger than in the city of Acapulco, Gro. (in the Southern region). Table A1 (in the appendix) summarizes the results of several unit-root tests applied to our table-egg price index series. In general, they provide evidence in favor of the stationarity of the series one trends are included and cross-sectional means are removed, which we emulate in our regressions with the inclusion of fixed effects.

**Figure 4. Price index of table eggs, 2011-2022**



Note: The brown line refers to the national average. The gray lines represent the price index series in each of the 55 cities. The 9 newest CPI cities do not have information before August 2018. The cities of Acapulco, Gro. and Fresnillo, Zac. are highlighted for illustrative purposes.  
 Source: Own elaboration using information from INEGI and SENASICA.

### 4.3 Distribution networks

To link HPAI outbreaks in producing municipalities with table-egg prices observed in final consumption markets we rely on mobilization records provided by SENASICA's General Directorate of Phytosanitary Inspection. These records are gathered by SENASICA as part of its phytozoosanitary regulations regarding the movement of agricultural products across Mexico. The data contains about 120,000 records of mobilizations across Mexico in 2021. Importantly, the data identifies origin and destination municipalities which allows us to elicit the distribution patterns that exists between producing and consuming areas. There are 94 origin municipalities contained in the data which jointly represent 73.5% of the national production of table eggs. If an origin municipality is linked to a destination municipality located within the CPI's geographical area of a city in our sample, then we say that the origin municipality has a distributions link with that city.<sup>10</sup> We discarded intermediary municipalities by dropping from the analysis origin municipalities with zero production of table eggs. In our analysis, we assume that the distribution links between origin and destination municipalities identified using 2021 data are representative of the 2011-2022 period. Figure A5 (in the Appendix) shows that the relative contribution of the main table-egg producing states has remained stable during this period. Thus, it is reasonable to assume that, in the same period, the commercialization networks between producing and consuming areas have also remained stable.

The diagram in Figure 5 shows the resulting distribution links aggregated from the city to the state level. At the center of it are the top 5 state producers which together concentrate 82.5% of the total production of table eggs in the country (see Figure 1). Lines connecting producing states with other states indicate that table-egg production moves from origin municipalities in producer states to destination municipalities in those other states.<sup>11</sup> The state of Jalisco, the largest producer, has commercialization links with cities mostly located in the North-

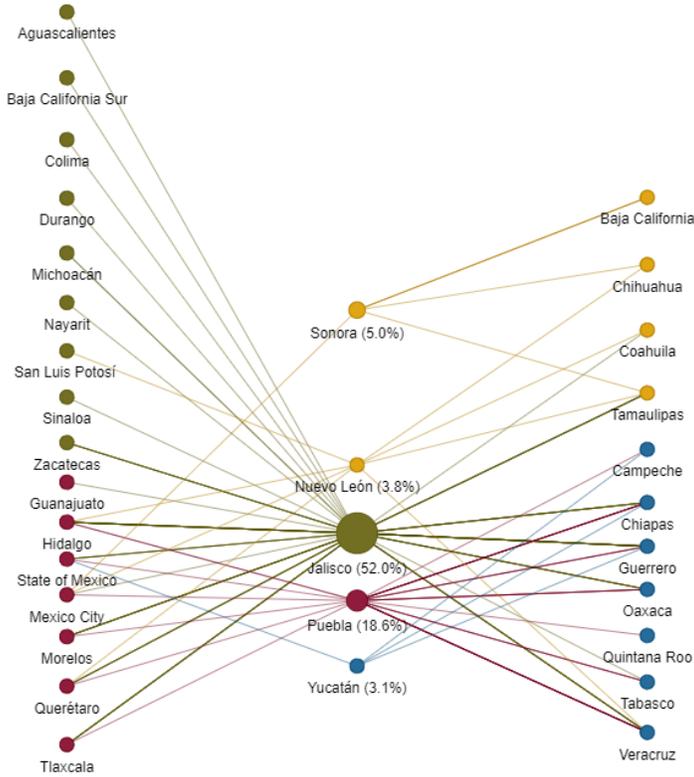
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<sup>10</sup> There are 55 CPI geographical areas, one for each city. These are formed by municipalities neighboring the city or large metropolitan areas formed by the several municipalities where the city is located (INEGI, 2018). A total of 1,090 Mexican municipalities fall within the boundaries of CPI geographical areas.

<sup>11</sup> To facilitate the analysis, the diagram omits the distribution links that exists among the top 5 producing states, yet, our mobilization data indicates that production of table eggs is also exchanged among them.

Central, Central and Southern regions. Jalisco by itself supplies table eggs to more than half of the Mexican states. Puebla, the second largest producer, supplies table eggs to cities located mostly in the Central and Southern regions. Smaller producing states, such as Sonora and Nuevo León, supply table eggs to cities mostly located in the Northern region. Similarly, most of the cities served by Yucatán are located in the Southern region.

**Figure 5. Commercialization patterns of table eggs among Mexican states in 2021**

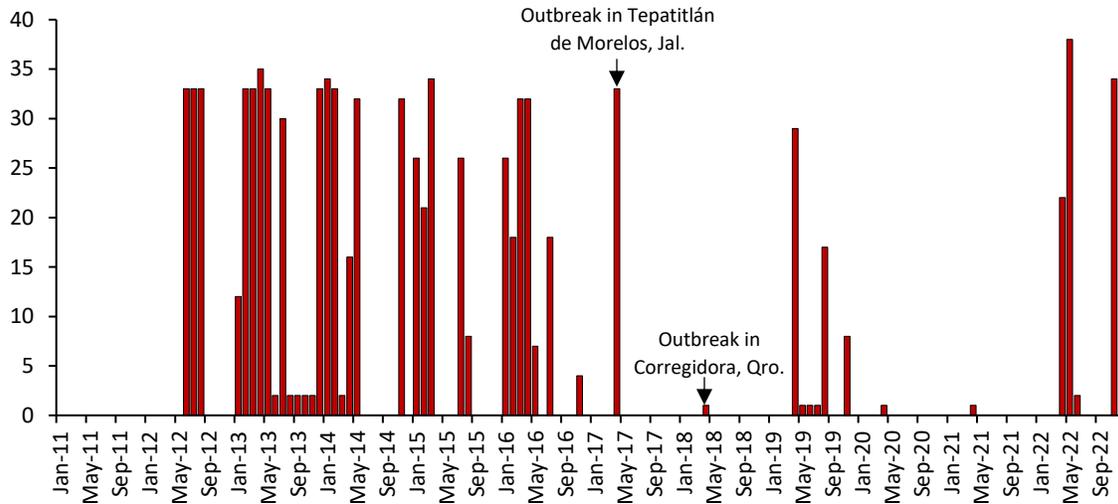


Note: Circles at the center of the diagram identify the top 5 producing states. The size of each circle is proportional to the contribution of each state to total production which is indicated in parenthesis (see Figure 1). Lines connecting states indicate that distribution links exist between origin municipalities in producing states and destination municipalities within the CPI geographical areas of the 55 cities in the sample.  
 Source: Own elaboration based on mobilization records provided by SENASICA.

Figure 6 shows that the frequency of cities linked to origin municipalities affected by HPAI increases as the importance of the affected municipality in the production and distribution of table eggs increases. For example, in April 2018 an HPAI outbreak affected a small producing municipality in Querétaro with distribution links with only one city in the sample. In contrast, in April 2017, an HPAI outbreak hit the municipality of Tepatitlán de Morelos in Jalisco, the largest producing municipality in the country (with about 15% of the total

production of table eggs) whose production is distributed to 33 cities in the sample. The highest frequency is observed in May 2022 when 38 cities in the sample had distribution links with origin municipalities affected by HPAI outbreaks in Puebla, Coahuila and Durango.

**Figure 6. Number of cities linked to origin municipalities affected by HPAI outbreaks**



Source: Own elaboration based on information from INEGI and SENASICA.

## 5. Empirical strategy

To identify the effect of HPAI outbreaks on the price of table eggs, we rely on fixed effects models using monthly data at the city level. The estimation covers the period from January 2011 to December 2022. We start by estimating an *exposure effect* using the following equation:

$$\ln Pegg_{it} = \alpha_i + \sum_{l=0}^{L=7} \beta_l HPAI_{i,t-l} + \tau_{year} + \gamma_{month} + \theta_{city}t + \varepsilon_{it} \quad (1)$$

where  $Pegg_{it}$  is the price index of table eggs in city  $i$  in year-month  $t$ . In equation (1), the variable  $HPAI_{it}$  is a dummy variable that identifies the occurrence of HPAI outbreaks in the municipalities supplying table eggs to city  $i$ . This variable was constructed using historical records of HPAI outbreaks in producing municipalities linked to each of the 55 cities in our sample using the distribution networks derived from SENASICA's mobilization records described in the previous section.  $HPAI$  takes the value of 1 if at least one the municipalities

supplying table eggs to city  $i$  is affected by an outbreak in year-month  $t$  and takes the value of zero otherwise. The specification includes up to 7 lags of  $HPAI_{it}$  to evaluate the dynamics of the effect that the occurrence of HPAI outbreaks may have on table-egg prices for a period of 8 months which is long enough to cover the amount of time required to repopulate the flock of laying hens in production after the slaughter caused by the outbreak. Typically, laying hens start to produce eggs at the age of 5-6 months (FAO, 2003). When an outbreak is consecutive and last for, say, 3 months, the variable  $HPAI$  takes the value of 1 for periods  $t$ ,  $t-1$  and  $t-2$  and zero for  $t-3$ , ...,  $t-7$ . However, HPAI outbreaks are intermittent events, not always consecutive. In such cases, the variable HPAI will take the value of zero in the intermediate months when no outbreaks are reported.

When estimating equation (1), an implicit assumption is that HPAI outbreaks have the same impact on table-egg prices regardless of their intensity. By construction, the HPAI dummy only reflects exposure to HPAI outbreaks without taking into account the total disruption they may have caused to egg-laying capabilities. In that sense, equation (1) delivers the effect of an average HPAI outbreak on table egg prices. To estimate an *intensity effect* of HPAI outbreaks on table-egg prices, we rely on the following alternative specification:

$$asPegg_{it} = \alpha_i + \sum_{l=0}^{L=7} \delta_l asHens_{i,t-l} + \tau_{year} + \gamma_{month} + \theta_{city}t + \varepsilon_{it} \quad (2)$$

where  $Hens_{it}$  is the total number of slaughtered birds in municipalities that supply table eggs to city  $i$  in month  $t$ . In equation (2) both, the price index of table eggs and the total number of slaughtered birds were transformed using the inverse hyperbolic sine function to preserve observations that would otherwise be lost when taking a logarithmic transformation.<sup>12</sup> As in equation (1), 7 lags of  $asHens_{it}$  are included in the estimation to allow for the possibility of lagged effects. The  $\delta$  parameters provide the elasticity of table-egg prices with respect to the number of birds slaughtered because of HPAI outbreaks.

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<sup>12</sup> With the inverse hyperbolic sine function the transformed variable  $\tilde{y}$  takes the form  $\tilde{y} = \ln(y + \sqrt{y^2 + 1})$ . Estimated coefficients can be interpreted as elasticities or semi elasticities as in a logarithmic transformation (Burbidge, Lonnie, and Leslie Robb, 1988).

In the estimation of equations (1) and (2) we control for unobserved time invariant factors affecting table-egg prices at the city level with city fixed effects ( $\alpha_i$ ). We also control for aggregate shocks affecting all the cities in our sample within the same year with year fixed effects ( $\tau_{year}$ ). We also include month fixed effects ( $\gamma_{month}$ ) to account for seasonal supply and demand shocks affecting table-egg prices.<sup>13</sup> Lastly, we control for city-specific linear time trends ( $\theta_{state}t$ ) to account for the increase of table-egg prices over time. In our identification strategy, we are unable to account for city-specific time-varying unobserved factors possibly correlated with both, the occurrence of HPAI outbreaks and table-egg prices.<sup>14</sup>  $\varepsilon_{it}$  corresponds to the error term. Standard errors are double-clustered at the city and region-year-month levels to account for serial correlation at the city level and for spatial correlation between cities located in the same region for a given time period. Accounting for spatial correlation is particularly important in our setting given the high geographical concentration of table-egg production. Table-egg prices in cities close to the main producing areas might strongly correlate during HPAI episodes. In general, clustering at the region level takes into account the high correlation that prices exhibit among neighboring states (Banco de México, 2022).

In our estimation, the main source of identifying variation comes from how table-egg prices change over time within a city in response to changes in exposure to HPAI outbreaks and in their intensity after netting out the influence of yearly and monthly shocks to prices. In simpler words, we are comparing how table-egg prices within a city change over time in periods with and without HPAI outbreaks. The use of temporal variation in both, prices and HPAI exposure for a given city is our source of identifying variation. The identifying assumption is that, conditional on  $X_{it}$ ,  $\alpha_i$ ,  $\tau_{year}$ ,  $\gamma_{month}$  and  $\theta_{city}t$ , past and present HPAI outbreaks and their intensity are not correlated with the rest of unobserved determinants of table-egg prices at the city level ( $\varepsilon_{it}$ ). In other words, HPAI outbreaks are events randomly

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<sup>13</sup> Thorough out the year, table-egg production displays a large seasonal component. Table-egg production is at its lowest during the first months of the year and at its highest by the end of the year (see Figure A6 in the Appendix). Our month fixed effects control for the effect of this seasonality on table-egg prices.

<sup>14</sup> An example of such factors could be the implementation of sanitary measures at the city level regarding the handling of table-eggs applicable to local wholesalers, retailers and consumers. The existence of such unobserved city-specific policies may result in different table-egg price sensitivities to the same HPAI outbreak.

determined. Avian influenza outbreaks are in fact exogenous unexpected events that are unlikely to correlate with unobserved determinants of table-egg prices as their occurrence mainly depends on the path followed by wild infected birds during migration. Also, the threat of novel unprecedented viruses is always present.

In our context, the use of a fixed effects strategy is more appropriate compared to, for example, a panel event study. HPAI outbreaks are intermittent events that tend to occur close to each other. For example, HPAI outbreaks may be detected in months  $t$  and  $t+1$ , disappear in month  $t+2$ , reappear in months  $t+3$  and disappear for good in month  $t+4$ . This intermittency prevents us from defining clear “pre” and “post” treatment periods because multiple treatments (HPAI outbreaks) may be experienced within the estimating window. For the estimation of a panel event study, we would ideally define a “post” period in which the treatment occurs for exposed cities continuously and a “pre” period in which the treatment is absent for all cities. Moreover, the set of exposed cities might be different across months as the occurrence of HPAI outbreaks is geographically heterogeneous. Some cities exposed in month  $t$  might not be exposed in month  $t+1$ . This also prevents us from having comparable sets of treated and non-treated cities within the estimating window. Our fixed effects strategy circumvents all of these difficulties by exploiting variation over time in HPAI exposure and table-egg prices within the same city during the whole sample period.

Prices are highly correlated among neighboring states (Banco de México, 2022). Due to this high correlation, we cannot rule out the possibility of spillovers effects in cities that are not directly exposed to HPAI outbreaks through commercialization. During HPAI episodes, it would be possible to observe increases in table-egg prices in cities not directly exposed to HPAI outbreaks just because of increased price expectations. Our estimates do not capture this indirect propagation mechanism. Because of this, we interpret our estimates as a lower bound of the total effect that HPAI outbreaks might have on table eggs.

Another shortcoming of our empirical strategy is the possibility of spillovers effects from one period to another when multiple HPAI outbreaks occur within our eight-month estimation window. Given the intermittence of HPAI outbreaks, it is possible that an outbreak

at time  $t-l$  is followed by another outbreak at time  $t$ . In such cases, the estimated coefficient of the lagged variable might be capturing a combination of the actual lagged effect of the outbreak that occurred at time  $t$  and the contemporaneous effect of the outbreak that occurred at time  $t-l$ . Our empirical strategy is unable to differentiate the contribution of each of these two different outbreaks to the increase in table-egg prices observed at time  $t$ . As a result, our parameter estimates for period  $t-l$  should be interpreted as the combination of the lagged effect of the outbreak that occurred at time  $t$  and the contemporaneous effect of any other HPAI outbreaks that may have occurred in period  $t-l$ .

## **6. The estimated effect of HPAI outbreaks on table-egg prices**

Parameter estimates of equation (1) are shown in Table 1. Results in column (1) elicit immediate and lagged effects of HPAI outbreaks on table-egg prices. Exposure to HPAI outbreaks cause an immediate increase in the price of table eggs of about 1.5% relative to the price that would be observed in a scenario without the disease. The lagged exposure effects are at first increasing and reach a maximum of 4.8% two months later. Afterwards, the effects are still positive but decreasing. Six months later, the price of table eggs is still 1.3% up relative to the price that would be observed in a scenario without the disease. By the seventh month the effect is still positive but not statistically significant. Thus, exposure to HPAI outbreaks increase table-egg prices for a period roughly equivalent to the amount of time necessary to repopulate the flock of laying hens after being decimated by the outbreak. Once table-egg production recovers, the exposure effect vanishes.<sup>15</sup>

Results in columns (2) and (3) suggest that the inclusion of additional lags does not change this conclusion as the effect for eight and ninth months is not statistically different from zero.

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<sup>15</sup> In Table A2, we present results obtained when city-by-year and city-by-month fixed effects are included in the regression. Results hold in general, however, the estimates are larger compared to our main specification. Also, the HPAI effect lasts longer. According to these estimates, the effect vanishes by the 9th month, not by the 7th. We argue that the larger estimates of the effects and the longer period for the effect to vanish are the result of limiting the identifying variation. Effectively, when including city-by-year and city-by-month fixed effects we are comparing the same city in the same month across different years but we are missing the variation that comes from comparing how prices evolve across months as a result of HPAI outbreaks. In our main specification, the identifying variation comes from within-city changes in table-egg prices over the whole sample period. In our main specification, we have more temporal variation to exploit which is important given that HPAI outbreaks are short-lived but typically last longer than a month.

In columns (4) and (5) of Table 1 we present additional results in which one and two leads of the HPAI dummy variable are included as additional regressors. We do this in order to test for anticipatory effects. In principle, if such events are truly exogenous and unexpected, prices should not react before they occur. Our results support this hypothesis as the coefficient estimates for the lead variables are not statistically significant. The exposure effect is limited to a time window of 7 months.

**Table 1. Estimates of the *exposure effect* of HPAI outbreaks on table-egg prices**

Variable	(1) 7 lags	(2) 8 lags	(3) 9 lags	(4) 7 lags, 1 lead	(5) 7 lags, 2 leads
HPAI <sub>t+2</sub>					-0.0092 (0.0075)
HPAI <sub>t+1</sub>				-0.0053 (0.0078)	-0.0048 (0.0076)
HPAI <sub>t</sub>	0.0150* (0.0084)	0.0151* (0.0085)	0.0165* (0.0084)	0.0170** (0.0082)	0.0154* (0.0085)
HPAI <sub>t-1</sub>	0.0441*** (0.0075)	0.0441*** (0.0075)	0.0438*** (0.0074)	0.0453*** (0.0079)	0.0443*** (0.0077)
HPAI <sub>t-2</sub>	0.0482*** (0.0077)	0.0482*** (0.0078)	0.0482*** (0.0078)	0.0471*** (0.0079)	0.0466*** (0.0079)
HPAI <sub>t-3</sub>	0.0427*** (0.0080)	0.0430*** (0.0082)	0.0432*** (0.0081)	0.0428*** (0.0081)	0.0415*** (0.0079)
HPAI <sub>t-4</sub>	0.0336*** (0.0080)	0.0336*** (0.0080)	0.0327*** (0.0079)	0.0332*** (0.0080)	0.0345*** (0.0078)
HPAI <sub>t-5</sub>	0.0216*** (0.0080)	0.0220** (0.0084)	0.0222*** (0.0082)	0.0216*** (0.0078)	0.0210** (0.0080)
HPAI <sub>t-6</sub>	0.0127* (0.0070)	0.0126* (0.0070)	0.0111 (0.0071)	0.0134* (0.0074)	0.0108 (0.0077)
HPAI <sub>t-7</sub>	0.0031 (0.0077)	0.0026 (0.0074)	0.0032 (0.0073)	0.0033 (0.0082)	0.0011 (0.0047)
HPAI <sub>t-8</sub>		0.0025 (0.0096)	0.0048 (0.0097)		
HPAI <sub>t-8</sub>			-0.0118 (0.0079)		
R <sup>2</sup>	0.8581	0.8674	0.8676	0.8632	0.8592
N	7,101	7,101	7,101	7,046	6,991

Note: Regressions are weighted by the share of each city on the national CPI. All the regressions include year fixed effects, month fixed effects and city-specific linear time trends. Standard errors (in parenthesis) clustered at the city and region-year-month level. \* p<0.10, \*\* p<0.05, \*\*\* p<0.01.

Source: Own estimation based on data from INEGI and SENASICA.

Table 2 presents parameter estimates of equation (2). These coefficients reflect the *intensity effect* of HPAI outbreaks. The contemporaneous intensity effect of HPAI outbreaks on table-egg prices is positive but not statistically significant (column 1). This result is at odds with the immediate exposure effect found in Table 1 and is possibly due to an expectation channel

captured in the exposure effect that is not reflected in the intensity effect. At first, egg-laying losses might not be as high or widespread as to get immediately reflected in table-egg prices. However, market prices may react to the uncertainty surrounding the magnitude and duration of HPAI outbreaks and increase immediately just because of its occurrence, as suggested by the *exposure effect*. In line with results in Table 1, the coefficient estimates for the lagged intensity effects are statistically significant for a time window of six months. They are also increasing at first, reach a maximum and decrease afterwards. The inclusion of additional lags (columns 2 and 3) and leads (columns 4 and 5) does not change this conclusion. The maximum increase in table-egg prices is also observed two months later when an increase of 1% in the number of slaughtered birds increases table-egg prices by 0.3%.

**Table 2. Estimates of the intensity effect of HPAI outbreaks on table-egg prices**

	(1)	(2)	(3)	(4)	(5)
Variable	7 lags	8 lags	9 lags	7 lags, 1 lead	7 lags, 2 leads
$asHens_{t+2}$					-0.0009 (0.0006)
$asHens_{t+1}$				-0.0008 (0.0006)	-0.0007 (0.0006)
$asHens_t$	0.0007 (0.0006)	0.0007 (0.0006)	0.0008 (0.0006)	0.0010 (0.0006)	0.0008 (0.0007)
$asHens_{t-1}$	0.0031*** (0.0006)	0.0031*** (0.0006)	0.0031*** (0.0006)	0.0033*** (0.0006)	0.0032*** (0.0006)
$asHens_{t-2}$	0.0033*** (0.0005)	0.0033*** (0.0006)	0.0033*** (0.0006)	0.0031*** (0.0006)	0.0031*** (0.0006)
$asHens_{t-3}$	0.0031*** (0.0006)	0.0031*** (0.0006)	0.0031*** (0.0006)	0.0031*** (0.0006)	0.0030*** (0.0006)
$asHens_{t-4}$	0.0024*** (0.0006)	0.0024*** (0.0006)	0.0024*** (0.0006)	0.0023*** (0.0006)	0.0024*** (0.0006)
$asHens_{t-5}$	0.0014** (0.0006)	0.0015** (0.0006)	0.0015** (0.0006)	0.0014** (0.0006)	0.0014** (0.0006)
$asHens_{t-6}$	0.0012** (0.0005)	0.0012** (0.0005)	0.0011** (0.0006)	0.0013** (0.0006)	0.0011* (0.0006)
$asHens_{t-7}$	0.0002 (0.0006)	0.0002 (0.0006)	0.0002 (0.0006)	0.0003 (0.0006)	0.0002 (0.0006)
$asHens_{t-8}$		0.0003 (0.0007)	0.0004 (0.0008)		
$asHens_{t-9}$			-0.0006 (0.0006)		
R <sup>2</sup>	0.8653	0.8654	0.8655	0.8613	0.8574
N	7,101	7,101	7,101	7,046	6,991

Note: Regressions are weighted by the share of each city on the national CPI. All the regressions include year fixed effects, month fixed effects and city-specific linear time trends. Standard errors (in parenthesis) clustered at the city and region-year-month level. \* p<0.10, \*\* p<0.05, \*\*\* p<0.01.

Source: Own estimation based on data from INEGI and SENASICA.

Table 3 shows the cumulative effect of consecutive HPAI outbreaks on table-egg prices. This calculation is equivalent to the summation of the estimated  $\beta$ 's (column 1 of Table 1) and  $\delta$ 's (column 1 of Table 2) obtained when estimating equations 1 and 2, respectively. The calculation includes the contemporaneous effect and the lagged effects for the first six months after the outbreak because the empirical evidence shown in tables 1 and 2 suggest that this is the time window in which HPAI outbreaks affect table-egg prices. The aim of this exercise is to approximate the price increase associated with an HPAI outbreak that lasts for 7 consecutive months. There are of course alternative scenarios in which HPAI outbreaks occur intermittently and not necessarily consecutively. Results in column 1 of Table 3 suggest that the cumulative exposure effect of an HPAI outbreak that lasts for 7 consecutive months, is equivalent to 22% relative to the price that would be observed in a scenario without the such outbreak. This is an extreme scenario rarely observed in our sample in which the average maximum duration of consecutive HPAI outbreaks is equal to 3.7 months. Accordingly, the cumulative exposure effect associated with the average duration would be somewhere between 10.7% and 15.0%. Results in column 2 of Table 3 table-egg prices would increase by 1.5% if the number of birds slaughtered increased by 1% every month over a 7-month time window. For the average outbreak duration of 3.7 months, the increase would be somewhere in between 0.7% and 1.0%

**Table 3. Cumulative effect of consecutive HPAI outbreaks**

	(1)	(2)
Months after the outbreak	Exposure effect (Equation 1)	Intensity effect (Equation 2)
0	0.0150* (0.0084)	0.0007 (0.0006)
1	0.0591*** (0.0117)	0.0039*** (0.0008)
2	0.1072*** (0.0154)	0.0072*** (0.0010)
3	0.1500*** (0.0203)	0.0103*** (0.0014)
4	0.1836*** (0.0243)	0.0126*** (0.0017)
5	0.2052*** (0.0280)	0.0141*** (0.0019)
6	0.2179*** (0.0316)	0.0153*** (0.0022)
<b>N</b>	<b>7101</b>	<b>7101</b>

Note: Standard errors estimated using the delta method.

Source: Own estimation based on data from INEGI and SENASICA.

Figure 7 provides a calculation of the average increase in table-egg prices that HPAI outbreaks may have caused during the sample period at the national and regional levels. This increase was obtained by evaluating the following expressions for every observation in the sample:

$$\text{Estimated exposure effect: } \ln\widehat{Pegg}_{it} = \sum_{l=0}^{L=6} \widehat{\beta}_l \text{HPAI}_{i,t-l} \quad (3)$$

$$\text{Estimated intensity effect: } \text{as}\widehat{Pegg}_{it} = \sum_{l=0}^{L=6} \widehat{\delta}_l \text{asHens}_{i,t-l} \quad (4)$$

where  $\widehat{\beta}_l$  and  $\widehat{\delta}_l$  correspond to the estimated coefficients displayed in column 1 of Table 1 and Table 2, respectively. In this calculation, the coefficient of the seventh lag is not included because our results suggest that HPAI outbreaks affect table-egg prices for a time window of seven months. After evaluating equations (3) and (4) for every observation in the sample, results were averaged nationally and regionally for each year-month in the sample using the share of each city on the CPI as weighting factor.<sup>16</sup>

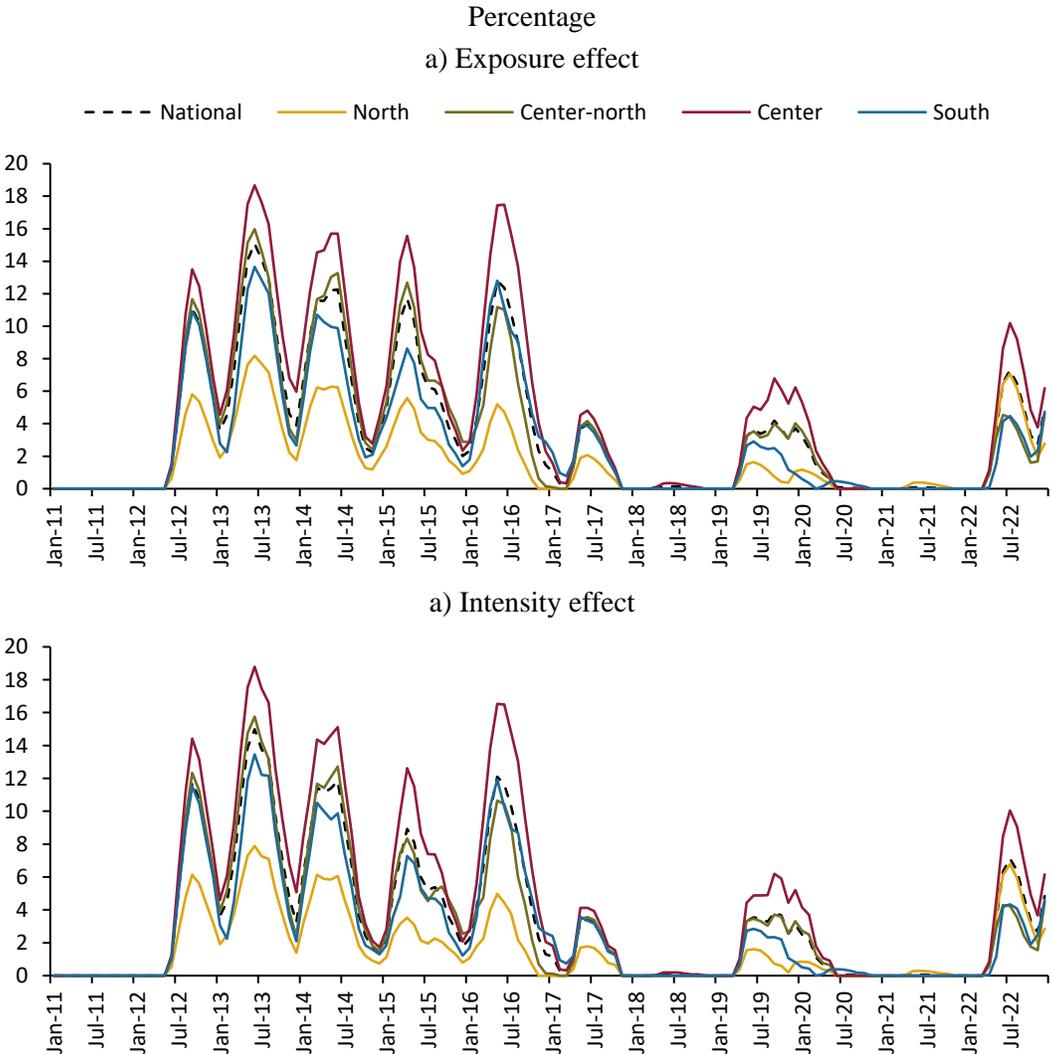
The estimated exposure (panel a) and intensity effects (panel b) are remarkably similar meaning that the increase in table-egg prices associated with HPAI outbreaks converges to a similar result regardless of the metric used to approximate it whether it is by exposition to an HPAI outbreak or by the intensity of it. Results suggest that at the national level, the estimated largest increases in table-egg prices were observed in June 2013 when table-egg prices were about 15.0% more expensive relative to the price that would have been observed in a scenario without HPAI outbreaks. In general, the effect of HPAI outbreaks was of considerable magnitude during 2012-2016 reaching estimated increases larger than 10.0% in several months. Between 2017 and 2022, the estimated impact of HPAI outbreaks on table-egg prices decreased. By the end of the sample period, in December 2022, we estimate that HPAI outbreaks may have increased the price of table eggs at the national level by about 4.8% relative to the price that would have been observed in a scenario without the disease. At the regional level, the North-Central and Central regions display the estimated largest

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<sup>16</sup> The weight used in the calculation of the regional average is the proportion that the CPI share of each city represents in the sum of the CPI shares of all of the cities located within the region.

increases. Together, these two regions concentrate 83.3% of the national production of table eggs (see Figure 1). Table-egg prices in cities located within these regions are more sensitive to HPAI outbreaks than table-egg prices in cities located outside because they are most likely to rely on local production to satisfy their demand of table eggs. As a result, during HPAI outbreaks it might be more difficult for them to substitute local production with production generated elsewhere, particularly because the supply-demand balance in other regions would be tight during HPAI episodes.

**Figure 7. Average increase in table-egg prices caused by HPAI Outbreaks**



Source: Own estimation based on data from INEGI and SENASICA.

The decrease in the sensitivity of table-egg prices to HPAI outbreaks observed in the second half of the sample period is mainly explained by a lower frequency of HPAI outbreaks coupled with a lower intensity due to a smaller concentration in the main producing areas. In 2012-2016 HPAI outbreaks were more frequent and mostly affected Jalisco, the main producing state, which is also highly connected with final consumption markets in several regions (see Figures 3 and 5). In contrast, in 2017-2022, HPAI outbreaks were less frequent and affected minor producing states. Most of the outbreaks that took place in this period occurred in 2022 (see Figure 3) and affected Coahuila, Durango, Yucatán and Sonora which jointly account for a smaller share of the national production of table eggs and are also less connected with final consumption markets (see Figure 5).

The lower frequency of HPAI outbreaks in recent years might also be explained, at least partially, by the adoption of more effective policies of prevention, control, surveillance, and eradication of HPAI outbreaks enforced and promoted by SENASICA which may have eventually resulted in smaller supply contractions and lower upward pressures in table-egg prices. In 2011, SENASICA published its general guidelines to diagnose, prevent, control, and eradicate HPAI outbreaks (DOF, 2011) and a manual of procedures to handle them (SAGARPA-SENASICA, 2011). The by-laws of the zoo sanitary law were published in 2012 (DOF, 2012d). This set of new policies reinforced DINESA by including faster notification methods and better surveillance, containment, and eradication procedures. According to SENASICA officials, these new policies and regulations were progressively implemented taking several months, even years, to take effect among producers, suppliers, product distributors, local authorities, and SENASICA personnel. Over time, the practices to handle HPAI outbreaks with DINESA improved not only in SENASICA but also among regulated firms and other authorities.<sup>17</sup> Importantly, SENASICA actively promotes the adoption of permanent biosecurity measures among producers.<sup>18</sup> Even if authorities acted

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<sup>17</sup> Interview with CPA personnel in May 27 of 2024.

<sup>18</sup> Biosecurity refers to measures aimed at protecting animal health in the face of the potential risks caused the introduction of know or unknow biological threats such as pests or micro-organisms like viruses. These include permanent staff training regarding HPAI prevention, the installation of peripheral fences to control access to the facility, a sanitary entrance module with showers and special clothes to disinfect personnel, disinfections of entering vehicles, methods to dispose or treat animal waste, cleaning protocols of the facilities and the flock,

promptly, a successful containment of HPAI outbreaks is highly dependent on the adoption of biosecurity measures by producers and firms involved in the transportation of table eggs. According to SENASICA, at the onset of the 2012 HPAI outbreaks, biosecurity practices among poultry producers were not yet widely adopted.<sup>19</sup> The adoption process improved in the following years while SENASICA continued promoting it and facilitating it.<sup>20</sup> As of 2023, 81% of poultry farms implement biosecurity measures (DINESA (13), 2023).

Vaccination has also played an important role in the recent management of HPAI outbreaks.<sup>21</sup> Vaccines reduce mortality and increase the production capacity of infected hens which mitigates production losses. Numerous vaccination campaigns have been launched as a response to HPAI outbreaks. The most recent one addressed the emergency caused by the appearance of the novel H5N1 virus in late 2022 when a total of 201 million vaccines were applied across 21 Mexican states (DINESA (12), 2023). Finally, another factor that could have contributed to a better management of HPAI outbreaks is the operational continuity of SENASICA and the different government and private parties that participate in the poultry value chain.

## **7. Conclusions**

Mexico is a country with a peculiar table-egg market. On the supply side, the geographical concentration of production is very high as only two states concentrate more than 70.0% of total production. This makes table-egg production particularly vulnerable to HPAI episodes

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storage guidelines for water and animal feed and constants surveillance of the flock to detect possible signs of contagion (DINESA (12), 2023).

<sup>19</sup> Interview with the head of SENASICA's Mexico-USA Commission for the Prevention of Aphthosa Fever and other Exotic Diseases (CPA by its Spanish acronym). January 30 of 2023.

<sup>20</sup> For this purpose, an updated version of the manual of procedures was published in 2015 with improved guidelines on biosecurity measures (SAGARPA-SENASICA, 2015).

<sup>21</sup> In order to be certified as HPAI free, poultry farms are required to have a veterinarian officially authorized by SENASICA (DOF, 2011). Veterinarians supervise the production process making sure it adheres to official regulations. They are also in charge of reporting possible cases of contagion and of soliciting emergency vaccination to SENASICA. If authorized, SENASICA buys and applies the vaccines. Producers could also buy and apply the vaccines themselves conditional on being authorized by SENASICA (Interview with SENASICA personnel, May 27 2024). However, total eradication is not guaranteed with vaccination as it does not prevent viral excretions among infected birds which could create a cycle of silent transmission (DINESA (1), 2022). Because of this, SENASICA has to be extremely cautious when authorizing vaccination in affected areas.

impacting high producing areas. On the demand side, Mexico is a heavy consumer of table eggs with 24 kg of annual per capita consumption, the highest in the world. This means that HPAI outbreaks may have important welfare consequences for Mexican consumers as the supply contractions they create may translate into higher table-egg prices and, potentially, lower protein consumption.

When assessing the impact of HPAI outbreaks on table-egg prices it is key to understand how the affected producing areas interact with the rest of the domestic market. When HPAI outbreaks occur, their impact on table-egg prices will depend on whether the affected areas concentrate a high or a low share of total production and on degree of commercial linkages between such areas and final consumption markets. The impact will also depend on the speed and efficacy of the actions taken for containment. Often, the necessary data to make such assessment is not readily available. In this paper, we overcome this data hurdle and estimate the effect of HPAI outbreaks on table-egg prices exploiting local variation on HPAI occurrences in producing areas and local variation on prices in final consumption markets. Our identification strategy relies on fixed-effects models in which table-egg prices observed at the city level are expressed as a function of exposure to HPAI outbreaks in producing municipalities. To link prices in cities with HPAI events in producing municipalities, we use distribution routes inferred from mobilization records between origin (producing) and destination (purchasing) municipalities.

Our estimates reveal a remarkable sensitivity of table-egg prices in final consumption markets to exposure to HPAI outbreaks affecting producing areas. The immediate effect is an increase of 1.5% relative the price that would be observed in a scenario without the disease. The lagged effects range from 1.3% to 4.8% with the maximum being achieved two months after the outbreak. The lagged effects persist for a total of seven months. A specification relying on the intensity of the HPAI outbreaks, as opposed to simple exposure, elicits the same findings. According to our estimates, price increases associated with HPAI outbreaks during our sample period were particularly high during 2012-2016 reaching levels higher than 15.0% nationally and at the regional level.

Over time, the affectations caused by HPAI outbreaks have decreased mainly because of a lower frequency of HPAI outbreaks in recent years possibly associated with the eventual adoption of improved and more effective policies of prevention, control, surveillance, and eradication of HPAI outbreaks enforced and promoted by SENASICA during the sample period, particularly those related to the adoption of good production practices and biosecurity protocols among producers. These measures were not immediately adopted by the poultry industry as whole because of the large heterogeneity of producers in terms of size and capabilities. The widespread adoption of good production practices and biosecurity measures among producers has taken some time to sink in. Eventually, the adoption of these and other practices may have translated into a more resilient table-egg supply and, thus lower price increases.

HPAI outbreaks represent a latent risk for the stability of table-egg production and prices in Mexico. In the past, these events have had large negative consequences in both outcomes and could continue to do so in the future. Their unpredictable timing, their uncertain rate of contagion, the possibility of mutating from a low to a high pathogenicity subtype, and the always-present threat of novel unprecedented viruses make HPAI events a source of large uncertainty for the Mexican poultry industry. The results of this article highlight the need of fast and efficient communication between the poultry sector, SENASICA, and other federal and state government authorities in order to control and eradicate the disease and implement the necessary actions to stabilize the supply of table eggs.

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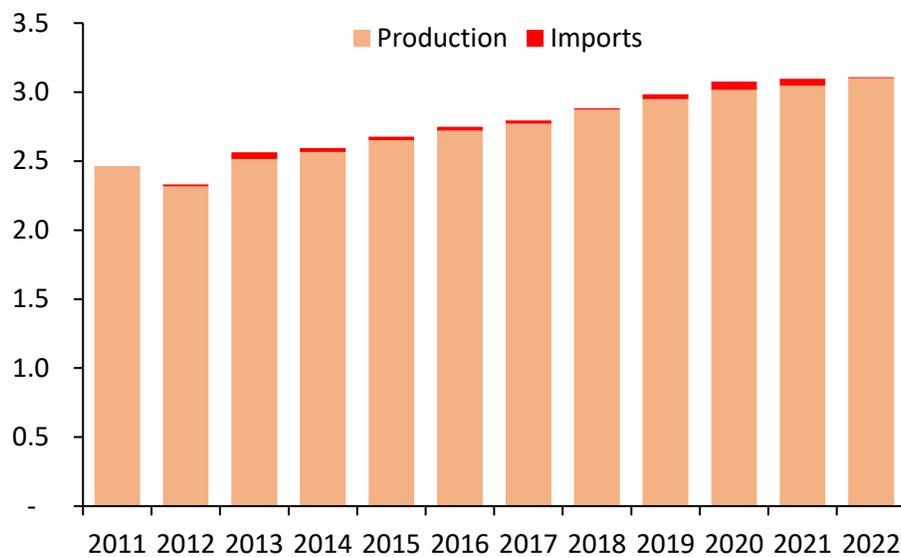
## 9. Appendix

### 9.1 Figures

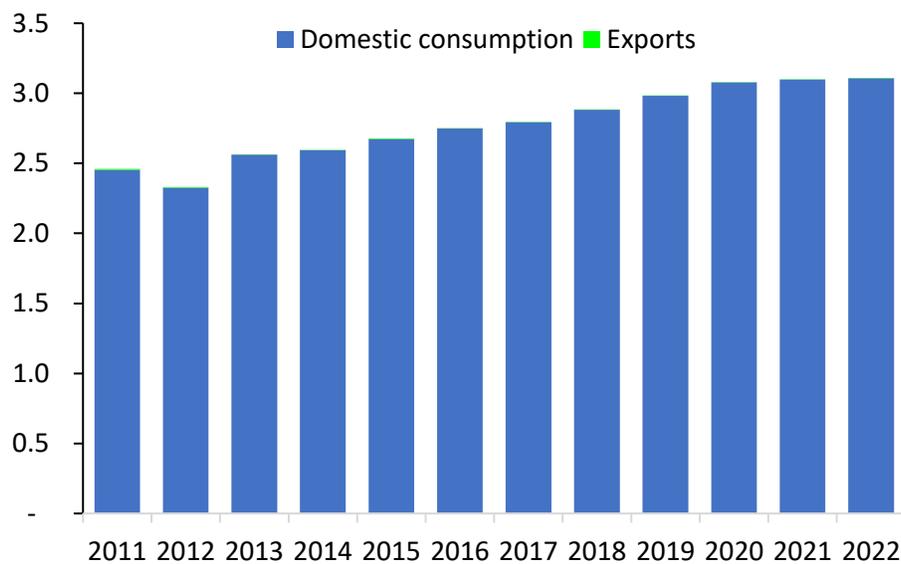
**Figure A1. Supply and demand of table eggs in Mexico**

Millions of metric tons

a) Supply

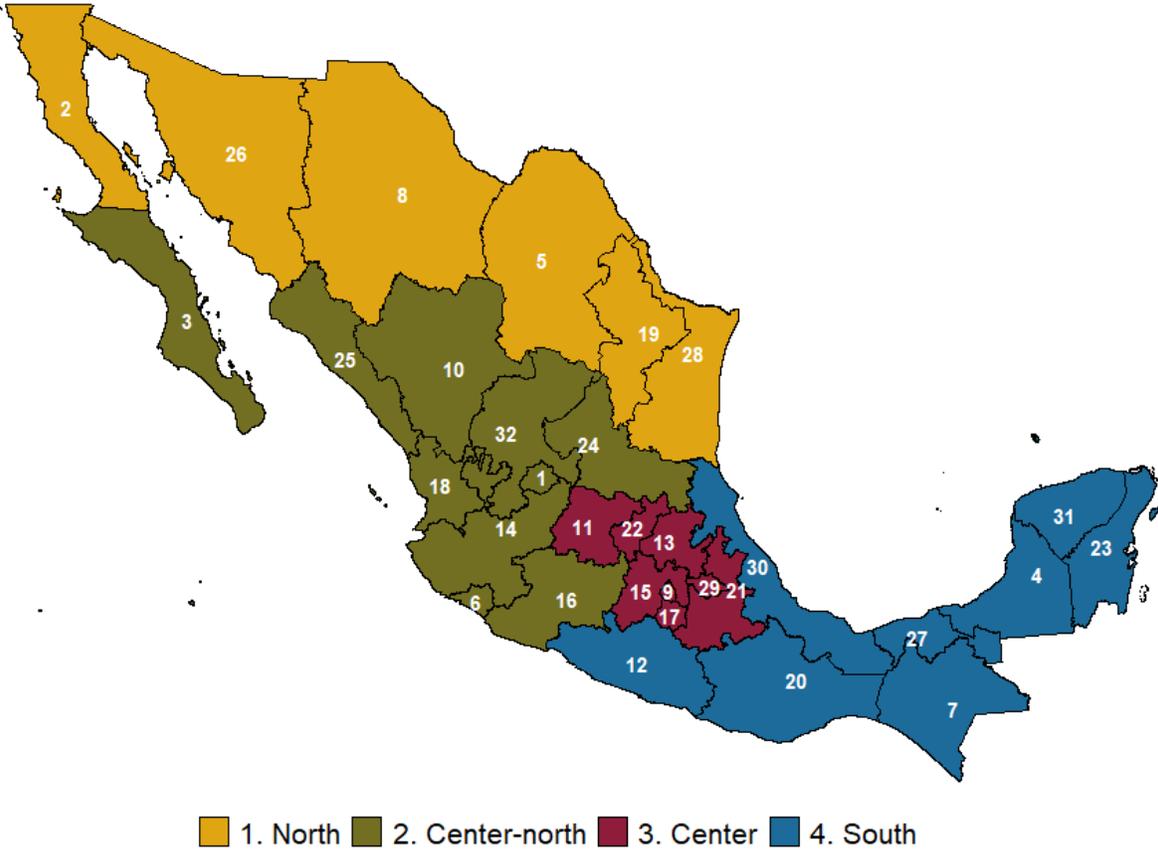


b) Demand



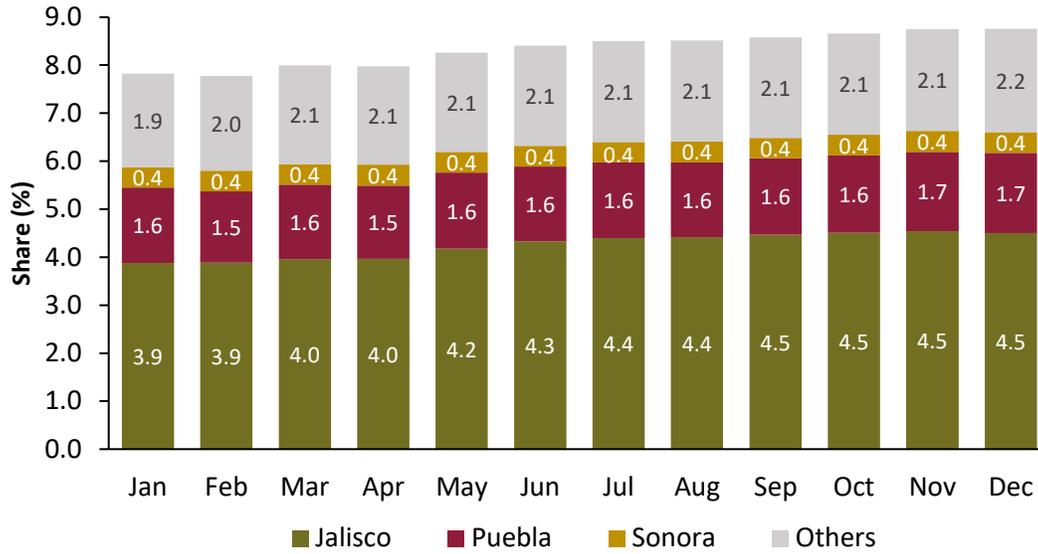
Source: Own elaboration using annual production and trade data from SIAP (2023).

**Figure A2. Regions of Mexico**



Note: State labels are as follows: 1=Aguascalientes, 2=Baja California, 3=Baja California Sur, 4=Campeche, 5=Coahuila, 6=Colima, 7=Chiapas, 8=Chihuahua, 9=Mexico city, 10=Durango, 11=Guanajuato, 12=Guerrero, 13=Hidalgo, 14=Jalisco, 15=México, 16=Michoacán, 17=Morelos, 18=Nayarit, 19=Nuevo León, 20=Oaxaca, 21=Puebla, 22=Querétaro, 23=Quintana Roo, 24=San Luis Potosí, 25=Sinaloa, 26=Sonora, 27=Tabasco, 28=Tamaulipas, 29=Tlaxcala, 30=Veracruz, 31=Yucatán, 32=Zacatecas.  
 Source: Own elaboration.

**Figure A3. Average distribution of table-egg production throughout the year**



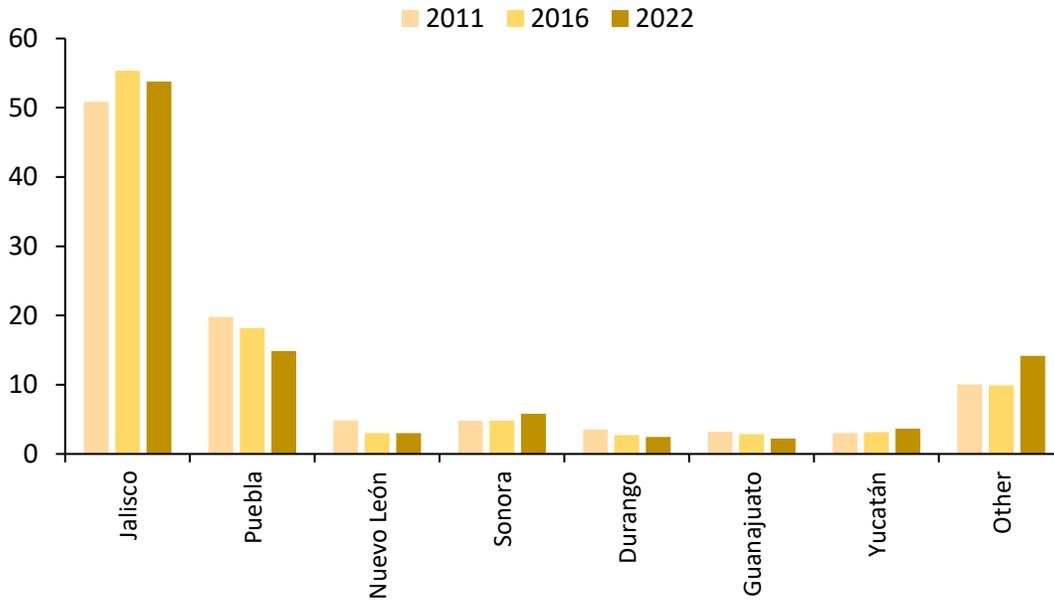
Note: The graph shows the average contribution of each state to the total production of table eggs throughout the year distributed across months. The sum of the percentages shown in all 12 months is equal to 100.  
 Source: Own elaboration using monthly production data from SIAP for the period 2004-2022.

**Figure A4. Location of cities**



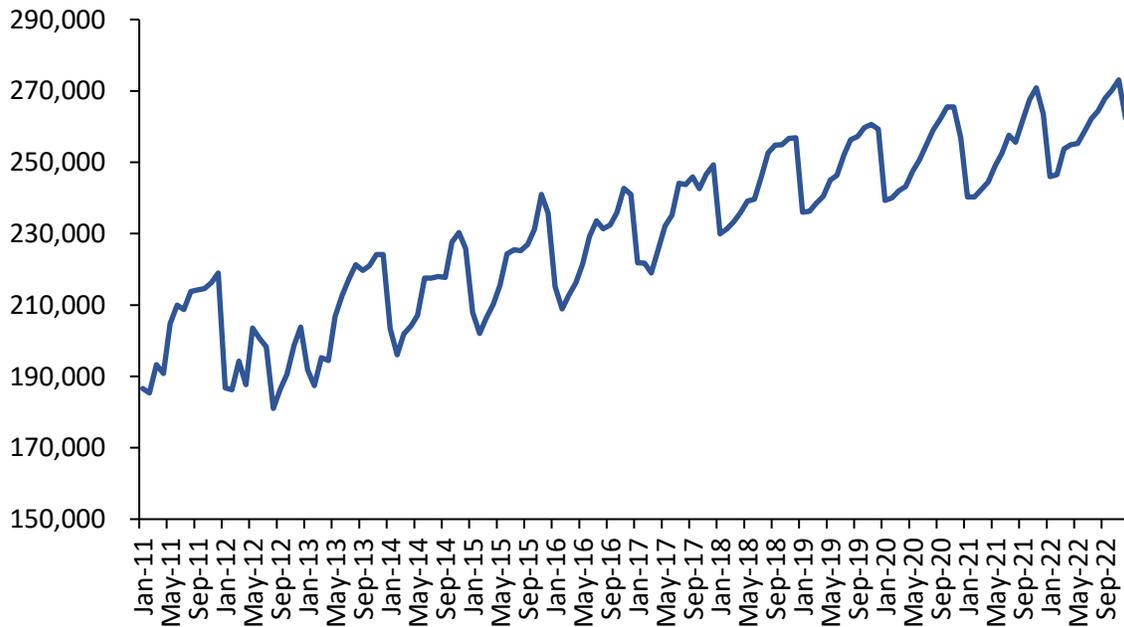
Note: The map shows the location of the 55 cities (red dots) contained in the sample. Each Mexican state is represented by at least one city.  
 Source: Own elaboration.

**Figure A5. State distribution of table-egg production in selected years**  
Percentage



Source: Own elaboration using annual production data from SIAP for the period 2006-2022.

**Figure A6. Monthly production of table eggs**  
Metric tons



Source: Own elaboration using monthly production data from SIAP for the period 2011-2022.

## 9.2 Tables

**Table A1. Unit root tests applied to the table-egg price index series**

Test Name	Null Hypothesis	Alternative Hypothesis	Statistic	Value	p-value	Panels
Levin–Lin–Chu	Panels contain unit roots	Panels are stationary	Adjusted t*	-23.0311	0.0000	46
Harris-Tzavalis	Panels contain unit roots	Panels are stationary	Z	-7.0748	0.0000	46
Breitung	Panels contain unit roots	Panels are stationary	lambda	-16.0074	0.0000	46
Im–Pesaran–Shin	All panels contain unit roots	Some panels are stationary	Z-t-tilde-bar	-23.7423	0.0000	55
Hadri LM test	All panels are stationary	Some panels contain unit roots	z	124.5824	0.0000	46
Fisher-type, based on augmented Dickey–Fuller tests	All panels contain unit roots	At least one panel is stationary	Inverse chi-squared P Inverse normal Z Inverse logit t L* Modified inv. chi-squared Pm	708.0316 -20.1550 -26.0926 40.3193	0.0000 0.0000 0.0000 0.0000	55
Fisher-type, based on Phillips–Perron tests	All panels contain unit roots	At least one panel is stationary	Inverse chi-squared P Inverse normal Z Inverse logit t L* Modified inv. chi-squared Pm	778.3334 -21.6241 -28.7398 45.0590	0.0000 0.0000 0.0000 0.0000	55

Note: All the test presented in this table are performed using the *xtunitroot* routine of Stata. In all of them, a time trend is included and panel means are removed. For the Fisher type tests, we assume that the data is generated by an AR(1) process and so, one lag of the dependent variable is included. The Levin–Lin–Chu, Harris-Tzavalis, Breitung and Hadri LM tests require strongly balanced panel data. Because of this, these tests are performed only on the 46 cities with complete information from January 2011 to December 2022.

**Table A2. Estimates of the effect of HPAI outbreaks on table-egg prices with city-by-year and city-by-month fixed effects**

	(1) 7 lags	(2) 8 lags	(3) 9 lags
HPAI <sub>t</sub>	0.0346*** (0.0051)	0.0374*** (0.0062)	0.0373*** (0.0061)
HPAI <sub>t-1</sub>	0.0616*** (0.0045)	0.0636*** (0.0050)	0.0637*** (0.0052)
HPAI <sub>t-2</sub>	0.0654*** (0.0042)	0.0680*** (0.0050)	0.0681*** (0.0052)
HPAI <sub>t-3</sub>	0.0594*** (0.0042)	0.0641*** (0.0054)	0.0642*** (0.0056)
HPAI <sub>t-4</sub>	0.0518*** (0.0039)	0.0533*** (0.0044)	0.0536*** (0.0048)
HPAI <sub>t-5</sub>	0.0404*** (0.0040)	0.0471*** (0.0055)	0.0472*** (0.0056)
HPAI <sub>t-6</sub>	0.0291*** (0.0036)	0.0298*** (0.0039)	0.0302*** (0.0044)
HPAI <sub>t-7</sub>	0.0277*** (0.0051)	0.0270*** (0.0053)	0.0271*** (0.0055)
HPAI <sub>t-8</sub>		0.0275*** (0.0057)	0.0273*** (0.0055)
HPAI <sub>t-9</sub>			0.0022 (0.0034)
R <sup>2</sup>	0.9011	0.9022	0.9022
N	7,101	7,101	7,101

Note: Regressions are weighted by the share of each city on the national CPI. All the regressions include city-by-year and city-by-month fixed effects. Standard errors (in parenthesis) clustered at the city level. \* p<0.10, \*\* p<0.05, \*\*\* p<0.01.

Source: Own estimation based on data from INEGI and SENASICA.