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The Effect of Natural Disasters on Hotel Demand, Supply and Labour Markets: Evidence from the La Palma Volcano Eruption

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Abstract

Natural disasters are an important deterrent factor for tourism activities from both supply and demand perspectives. This paper studies the short-term effect of a volcano eruption on hotel demand, supply and hospitality labour in La Palma (Spain), an island economy that is highly dependent on the tourism sector. Based on a monthly panel dataset, we employ seemingly unrelated difference-in-differences (SUR-DiD) to identify the distinct responses of these three outcomes both during and post eruption. We are particularly interested in examining the asymmetry in their elasticities to the shock, which serve as indicators of disaster resilience. Potential spillover effects on nearby islands are also examined. We find that the eruption resulted in significant yet asymmetrical drops in international demand, number of hotels opened, and hospitality workers hired. Our findings inform about the resilience of the tourism industry to natural disasters, offering relevant insights about heterogeneous effects depending on exposure to the event.

Keywords Natural disasters · Tourism-led economy · Resilience · Recovery from disaster

JEL Classification R11 · R23 · Z30

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1 Introduction

How do volcanic eruptions affect tourism markets and hospitality labour? Are the effects on tourism supply and demand symmetric? A large body of literature has shown that natural disasters produce important contemporaneous and middle-term losses in economic growth for affected areas (Cavallo et al. 2013; Ishizawa and Miranda 2019; Silva et al. 2023; Strobl 2011). Tourism-dependent economies are particularly vulnerable to these events since disasters directly damage public infrastructures and supply facilities (Kim and Marcouiller 2015; Kunze 2021) and deter tourism demand due to risk aversion (Park and Reisinger 2010). Among the different types of disasters, volcanic eruptions have been recognised as one of the most impactful events for tourism flows (Rosselló et al. 2020). However, we still know little about how volcanic eruptions disrupt tourism markets, the recovery dynamics and potential contagion effects on nearby areas.

The goal of this paper is to assess the short-term effects on the tourism industry of the September 2021 eruption of the *Cumbre Vieja* volcano. Specifically, we focus on analysing the resilience to the disaster displayed by hotel demand, supply and the related labour market. We exploit the exogenous occurrence of the natural shock to examine the vulnerability of these factors as well as short-term resilience both *during* and *post* eruption. We also investigate potential spillover effects on nearby islands that belong to the Canary archipelago using the Balearic Islands as the control group. This is particularly timely, as the literature is inconclusive about the indirect costs of a disaster resulting from spillover mechanisms (Lazzaroni and van Bergeijk 2014).

La Palma is an island in the Canary archipelago (Spain), and its economy is highly dependent on the tourism sector. With 708 square kilometres and 84,000 inhabitants, the island received 173,378 tourists in 2019 (INE 2022). On 19 September 2021, the *Cumbre Vieja* volcano erupted, lasting until the middle of December. During the 85 days it was erupting, the volcano emitted between 600 and 11,000 daily tonnes of sulfuric dioxide. According to the Volcanological Institute of the Canary Islands, the emissions of sulfuric dioxide to the atmosphere were equivalent to the total emissions of the 28 European countries in 2019 (El Mundo 2021). Nonetheless, the airport of La Palma was open during 90% of the time the volcano was erupting. Although no casualties were reported, the eruption caused extensive damages worth around 842 million euros and high environmental pollution (Gobierno de España 2022).

To conduct our analysis, we use a monthly panel dataset on the number of foreign tourists, hotel establishments opened, and hotel employees between September 2020 and December 2022 in 12 tourist zones in the Canary (treated group) and the Balearic (control group) Islands. The Balearic Islands are chosen as the control group because (i) they are located far away from La Palma, ruling out contagion effects, and (ii) they share a similar endowment of hedonic attributes together with a common specialisation in tourism services, hence providing a better overlap in unobservable confounders than other destinations. Our identification strategy combines a difference-in-differences (DiD) research design with a seemingly unrelated regression (SUR) that allows for common unobserved shocks affecting the three interrelated outcomes.

There are two compelling reasons that make our case study of significant interest. First, the Canary Islands are a volcanic archipelago that is highly dependent on the tourism sector. Foreign receipts from tourism activities are major determinants of capital accumulation and economic growth for island economies (Schubert et al. 2011; Seetanah 2011), which typically lag behind their inland counterparts within the same country due to their remoteness (Del Gato and Mastinu 2018). Empirical studies on regional resilience following natural disasters generally find that economic diversification attenuates the short-term impact and persistence of the shock (Coulson et al. 2020). As such, the economic effects in the region from the volcano's eruption are predicted to be substantial. This shock is not only detrimental and disruptive for the industry itself but also likely propagates to the whole economy through the corresponding multiplier effects on other related sectors (Figini and Patuelli 2022; Xu et al. 2020) and the positive link between tourism and international trade (Santana-Gallego et al. 2011). Moreover, tourism represents a major source of tax revenues for island economies, as recently documented by Mohan and Strobl (2023).

Second, previous works have investigated the impacts of earthquakes (Cheng and Zhang 2020; Huan et al. 2004; Huang and Min 2002; Mazzocchi and Montini 2001), tsunamis (Fukui and Ohe 2020; Reddy 2005), hurricanes (Kim and Marcouiller 2015) or tropical storms (Schmude et al. 2018) on tourism demand, but the effects of volcanic eruptions have been scarcely studied. Rosselló et al. (2020) are among the few who have shown that volcanic eruptions are associated with the greatest declines in tourism arrivals.[1] However, the impact of volcanic eruptions on hospitality labour and supply remains underexplored to date.

The paper adds to a large volume of literature on the economic effects of natural disasters on local economies (Kim and Marcouiller 2015; Lima and Barbosa 2019; Strulik and Trimborn 2019; Xiao 2011). We expand existing knowledge about the impacts of natural disasters on tourism demand (Huang and Min 2002; Mazzocchi and Montini 2001; Rosselló et al. 2020) and labour markets (Belasen and Polachek 2008, 2009; Ewing et al. 2009; Fouzia et al. 2020; Mendoza and Jara 2022) by jointly examining the distinct temporal trajectories followed by hotel demand, supply and the hospitality labour market *during* and *post* the volcano's eruption. We assess potential asymmetric elasticities across areas, over time and among outcomes. In doing so, we are among the first to uncover how natural disasters shift accommodation supply and the derived labour through plausible adjustments in capacity utilisation as theoretically postulated by Butters (2020). In this respect, there is no evidence on how natural disasters affect tourism labour markets. This represents an important research gap that we aim to fill.

Our estimates reveal a significant decline in La Palma's international tourism demand, both during (−61.0%) and after (−49.7%) the eruption. Hotel supply exhibits a larger post-eruption decrease (−39.4%) compared to the during-eruption period (−23.4%). Concurrently, the hotel workforce experiences a 32.0% decline during the eruption but a 45.6% drop afterwards. Based on our results, we provide an estimate of the economic losses of the volcano for the hospitality sector, as done by related works in different settings (Brown et al. 2021; Chen et al. 2021; Schmude et al. 2018). Our findings are thus informative about the vulnerability and resilience of small island destinations and can enlighten policymakers about post-disaster recovery and the development of contingency planning.

The rest of the paper is organised as follows. In Sect. 2, we present our case study. In Sect. 3, we describe the dataset and variables, together with some descriptive statistics. The empirical strategy is described in Sect. 4. Next, Sect. 5 presents and discusses the

[1] Pérez-Granja et al. (2022) is the only work of which we are aware that has investigated the impact of the volcanic eruption of *Cumbre Vieja* on tourism expenditures at the individual level. They present evidence of a positive shift in expenditures among those that continued visiting La Palma Island following the eruption, which they attribute to empathy. Our work is quite different in scope as we look at the dynamics of hotel demand, supply, and labour input at the aggregate level.

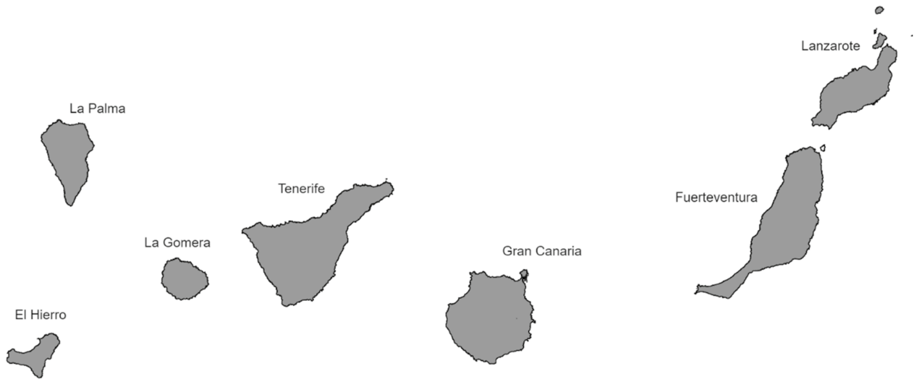

Fig. 1 The Canary archipelago

estimation results. The last section summarises the main findings of the paper and concludes with some policy implications.

2 Background

Our study area is the Canary Islands, a well-known sun and beach tourist destination in the North Atlantic tropical region composed of seven islands: La Palma, El Hierro, La Gomera, Tenerife, Gran Canaria, Fuerteventura and Lanzarote.[2] Figure 1 maps the geographic position of each of the islands. The archipelago has 2.2 million inhabitants and an area of 7447 square kilometres. It has a volcanic origin, and together with Cabo Verde, Madeira, Azores, and the wild islands, it composes the Macaronesia region, a group of archipelagos in the Atlantic Ocean.

The region is highly specialised in tourism services, which has been a driving force of its economic development in the last decades (Capó-Parrilla et al. 2007a). Its all-year round good weather conditions and thermal comfort make it an attractive destination (Carrillo et al. 2022), particularly for the sun and beach tourism segment. The region annually receives around 10 million tourists, out of which 75% are foreign visitors (INE 2022). According to EXCELTUR (2020), the tourism industry in 2019 represented around 40% of its total employment and 35% of the regional GDP. Tourism inflows have been shown to correlate with international trade (Santana-Gallego et al. 2011), and a consideration of the multiplier effects on other related sectors leads to an estimation that tourism generates around 75% of the GDP of the Islands (Vayá et al. 2023).

La Palma is the most volcanically active region of the archipelago, hosting half of all past eruptive events (Carracedo et al. 2022). The most recent eruption dates to 19 September 2021 when the *Cumbra Vieja* volcano (located in the municipality of El Paso in the central-western part of La Palma Island) started to erupt. The *Cumbre Vieja* eruption stands out as the most prolonged volcanic event to have occurred in La Palma in the last five centuries. According to official reports, during the 85 days it was active, around 7000 people were evacuated, 73.8 kms of roads were buried by lava and around 3000 buildings

[2] There is an additional island called La Graciosa and other three non-habited *islotes*. However, from a political viewpoint, the Canary Islands are considered to be composed of only seven islands.

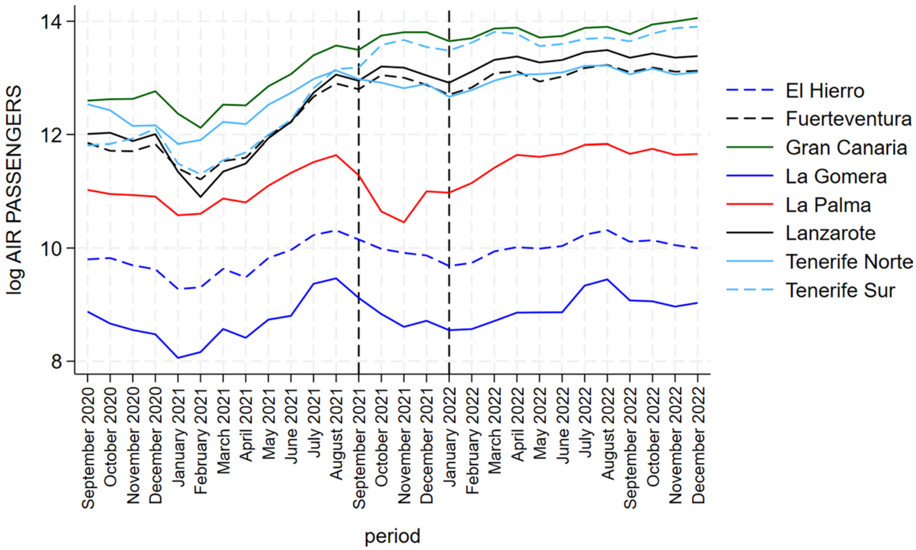

Fig. 2 Air passengers (in logs) departing and arriving at the eight airports in the Canary Islands between September 2020 and December 2022

across an area of 12.2 square kilometres were destroyed in total (Gobierno de España 2022). Moreover, about 2300 people lost their houses and had to stay with friends or relatives. The overall losses have been estimated to be around 842 million euros, with building damage accounting for approximately 20% of the losses and road infrastructure damage accounting for approximately 27%.[3] The eruption received great attention and coverage by both Spanish and international media like the BBC or the Wall Street Journal.

In addition to the direct damages caused by lava flows (159 million cubic metres), the eruption also affected air quality and public health (Filonchyk et al. 2022). A study by Milford et al. (2023) revealed the existence of high concentrations of SO_2, PM_{10} and $PM_{2.5}$ in La Palma Island during and after the *Cumbre Vieja* volcanic eruption, persisting for several weeks and exceeding normal levels. The presence of these aerosols in the air were observed up to 140 kms away on the neighbouring Island of Tenerife (Milford et al. 2023). On 13 December, the volcano finally stopped erupting. An overview of the eruption can be found in Longpré (2021) and Carracedo et al. (2022).

The airport of La Palma (located on the eastern coast of the island) was nevertheless open during 90% of the time the volcano was erupting, and 74% of the flights scheduled between middle September and middle December were taken (AENA 2021). Figure 2 plots the evolution of air passengers arriving and departing from the eight airports in the Canary Islands (in logs) between September 2020 and December 2022. The data comes from monthly reports provided by AENA. We see that during the eruption period there was a notable drop in air passengers on La Palma Island, with a partial recovery after the volcano stopped erupting (January 2021) and onwards. Interestingly, the close islands of La Gomera and El Hierro also exhibited a shift in their air passengers' trends during

[3] These losses can be broken down into 228 million euros from damage to road infrastructure, 200 million euros from the destruction of banana crops and 165 million euros due to the destruction of buildings (Gobierno de España 2022).

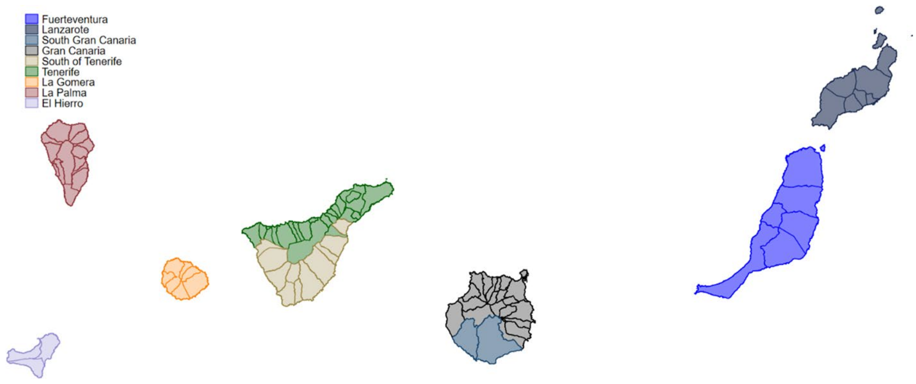

Fig. 3 Municipality composition of each tourist zone in the Canary Islands

the eruption period. Although this data refers to the aggregate of arrivals and departures (including residents), it suggests that the potential negative effects of the volcano on tourism arrivals might have spilled over to La Palma's nearby islands through risk avoidance mechanisms on the demand side (e.g., Huan et al. 2004; Park and Reisinger 2010) or airline supply distortions associated to the presence of ash in the air.

3 DATA

3.1 Data Sources, Geographical Setting and Study Period

We use official panel data on the monthly number of foreign visitors lodged at hotels, the number of hotel establishments opened, and hotel workers hired in relation to twelve tourist zones.[4] The data is drawn from the Hotel Occupancy Survey conducted by the Spanish National Statistics Institute (INE) at the tourist zone level.[5] As defined by the INE, a tourist zone is a regional aggregation in-between islands and municipalities that brings together areas characterised by similar tourism demand and supply patterns.[6]

The Canary Islands are composed of nine tourist zones: Fuerteventura, Gran Canaria, South of Gran Canaria, La Gomera, El Hierro, La Palma, Lanzarote, Tenerife and South of Tenerife. Thus, the two main islands of Gran Canaria and Tenerife are split into two distinct zones whereas each of the other islands are considered as single zones.[7] All the

[4] In the main analysis, we focus on foreign visitors because previous works have shown that natural disasters are more of a deterrent for international than for domestic tourists (Barbhuiya and Chatterjee 2020; Rosselló et al. 2020). Nonetheless, for robustness, we also consider the total number of tourists including domestic ones (see Sect. 5.2).

[5] Although peer-to-peer accommodations (e.g., Airbnb) are also popular, hotels are by far the most important type of accommodation in the Canary Islands, representing around 72.5% of the hospitality market (INE 2022). Notwithstanding this, for robustness, we also use data for private apartments (see Sect. 5.2). This data is not used in the main analysis because we avail a lower number of cross-sectional units (tourist zones) as compared to hotels.

[6] Ideally, we would like to use data at the municipality level. Unfortunately, there is no available monthly data on the number of hotels and hotel workers at such a geographical disaggregation.

[7] For the island of El Hierro, information on the relevant variables was collected from the Canary Institute of Statistics (ISTAC).

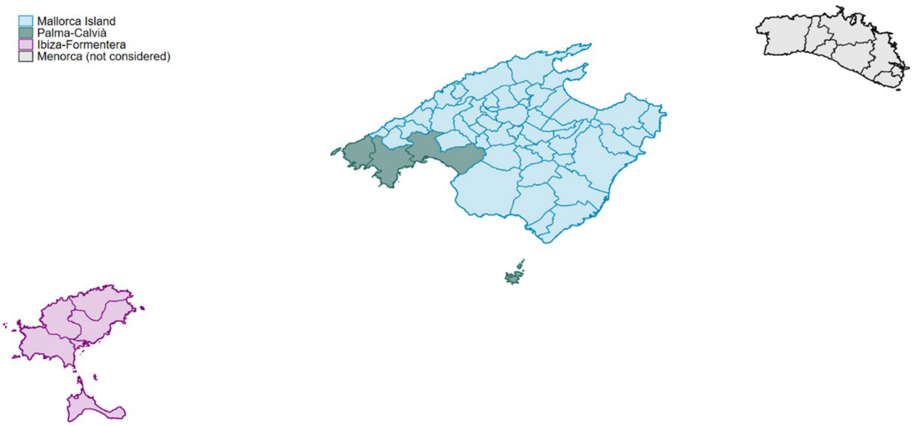

Fig. 4 Municipality composition of each tourist zone in the Balearic Islands

municipalities are assigned to one of the zones so that the nine zones gather all the municipalities on the islands. Figure 3 illustrates the municipality composition of each zone in the Canary Islands. In the case of the Balearic Islands, we work with three tourist zones: Mallorca Island, Palma-Calvià (gathering the capital city of Mallorca Island plus some neighbouring municipalities) and the islands of Formentera and Ibiza.[8] Figure 4 plots the municipality composition of each zone of the Balearic archipelago. The full list of the municipalities that integrate each zone in the Balearic and Canary archipelagos is presented in Online Appendix, Table A1.

Because of the break in the series caused by the COVID-19 pandemic in 2020 and the associated lockdown implemented in Spain between March and June 2020, we only consider one year prior to the volcano's eruption. Accordingly, our dataset refers to the period September 2020–December 2022 and involves a total of 336 observations (12 zones × 28 periods). This choice was aimed at preventing the confounding effect of the pandemic in the pre-eruption period.

Nonetheless, it is important to acknowledge that some mobility restrictions were imposed due to a surge in COVID-19 infectious cases between the last quarter of 2020 and the first quarter of 2021. These restrictions might have affected the inflow of tourists to the tourist zones (e.g., Boto-García 2023). Between November 2020 and May 2021, a third State of Alarm was in force that allowed regional authorities to enforce curfews and mobility restrictions, particularly during nighttime hours (*Real Decreto 926/2020, de 25 de octubre*). Figure 5 presents time series graphs of the percentage change in daily mobility in (i) retail and recreation, (ii) transit at stations, (iii), workplaces and (iv) groceries and pharmacies with respect to a pre-COVID-19 baseline period in the Balearic and the Canary Islands (Las Palmas and Tenerife Islands) between 1 March 2020 and 31 December 2021.[9] We can see that the three provinces exhibited similar trends in mobility rates relative to the baseline period between November 2020 and May 2021. As such, it seems

[8] INE also considers the island of Menorca as a tourist zone. However, it is discarded because the raw data contains several missing values, especially during the low season.

[9] The baseline period is computed as the average mobility per day of the week between 1 March 2020 and 2 June 2020. The data is drawn from Google Community Mobility Records (2023).

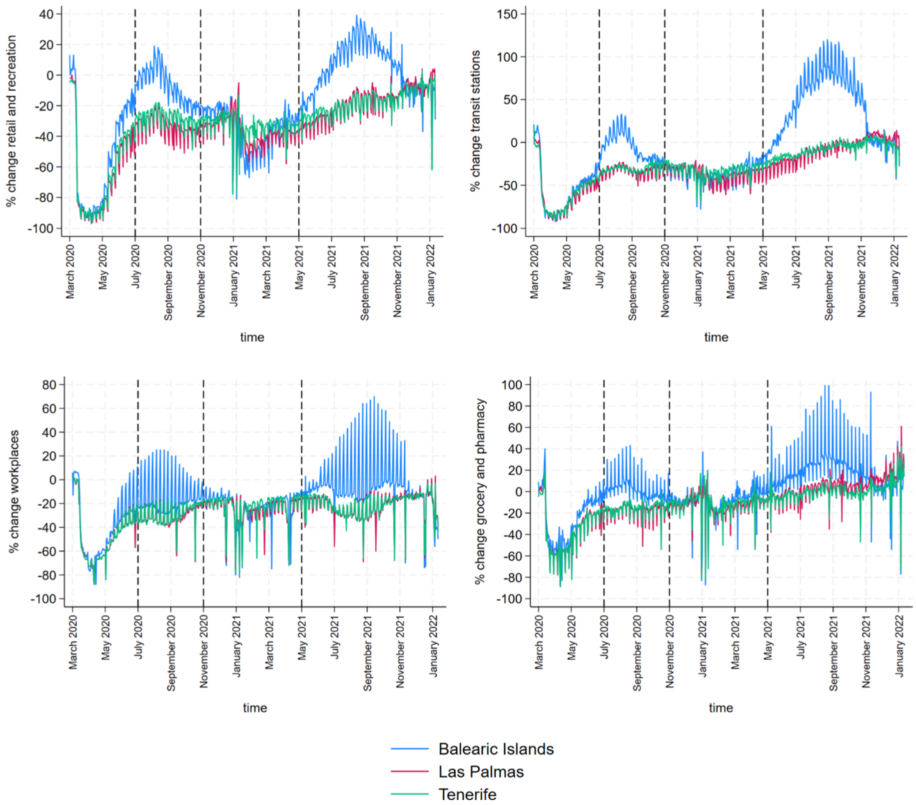

Fig. 5 Daily percentage change in mobility in retail and recreation (upper left panel), transit at stations (upper right panel), workplaces (bottom left panel) and grocery and pharmacy (bottom right panel) between 1 March 2020 and 31 December 2021. The figures plot the percentage change in daily mobility with respect to a baseline period of five weeks (3 January 2020–6 February 2020) in the provinces of the Balearic Islands (tourist zones included: Mallorca Island, Palma-Calvià, and the islands of Formentera-Ibiza), Las Palmas (tourist zones included: Gran Canaria, South of Gran Canaria, Fuerteventura and Lanzarote) and Tenerife (tourist zones included: Tenerife, South of Tenerife, El Hierro, La Palma and La Gomera)

mobility restrictions that were imposed during that period have almost equally affected the two archipelagos. Therefore, we do not envisage pandemic-related policies to pose a major threat to identification.

3.2 Treated and Control Units

Cumbra Vieja is located on La Palma Island. Therefore, La Palma represents the *treated* unit in our empirical setting. According to the extant literature, volcanic eruptions have a negative impact on ecosystems near the volcano, with detrimental effects on the vegetation cover and quality of lands and, therefore, on the quality of living animals (e.g., Filonchyk et al. 2022). During the eruption period, a large column of smoke and ashes moved to the atmosphere and towards the Iberian Peninsula, potentially affecting the nearby islands in the archipelago. Apart from their geographical proximity, the rest of the islands in the Canary Islands belong to the same Autonomous Community and are likely to share high demand linkages and mobility of production factors. On these grounds, there is scope for potential spillover effects on the economy of these islands, which are mostly tourism led. Therefore, the eight remaining tourist zones of the Canary Islands are considered as a potentially treated group (*Pot.treated*).

As anticipated in the Introduction, the Balearic Islands seem to be the most appropriate comparison group. Because they are located further away (in the Mediterranean Sea, about 2700 km from La Palma), we rule out potential spillover effects on them. Moreover, both the Canary and the Balearic archipelagos are specialised in sun and beach tourism that heavily relies on the exploitation of natural resources.[10] In this regard, both archipelagos have been shown to suffer from symptoms of the well-known Dutch disease (Capó-Parrilla et al. 2007b).

An alternative strategy could be to consider other sun and beach tourist zones in the Spanish Peninsula as the control group. However, the appropriate identification of the effects of the eruption requires treated and untreated units to be similar in their hedonic characteristics (particularly in the tourism context) and to follow parallel trends in outcomes in the pre-eruption period. Some studies have indicated that island regions exhibit different economic growth dynamics than mainland areas because their geographic isolation and endowment of natural amenities make them more dependent on tourism receipts (Mazzola et al. 2022). For these reasons, we opted for a control group composed of other insular non-treated areas belonging to the same country.[11] Consequently, the three zones in the Balearic Islands (Mallorca Island, Palma-Calvià and the islands of Formentera and Ibiza) constitute the *non-treated* (pure control) group.[12]

The volcano erupted from 19 September to 13 December 2021. We consider the period between September 2020 and August 2021 as the pre-treatment period. Since the effects of the volcano on hotel demand and supply are likely to differ depending on whether the volcano was active or not, we distinguish two treatment periods: during eruption (September 2021–December 2021, denoted by *During*) and post eruption (January 2022–December 2022, denoted by *Post*).

3.3 Summary Statistics

Table 1 presents descriptive statistics of the three variables of interest, disaggregated by group (La Palma, potentially treated and non-treated) and period (pre-eruption, during and post-eruption). Hotels in La Palma hosted on average 1,234 foreign tourists per month during the pre-treatment year, with around 12 hotel establishments and 257 workers. The corresponding figures for the potentially treated and the non-treated groups are notably larger given their greater size, although there is quite a bit of similarity between them. Strikingly, the number of foreign tourists, hotels open and workers employed are larger during and post

[10] According to official statistics by INE from the Tourist Movement on Borders Survey, the share of foreign tourists travelling for business purposes in 2021 was 7.0% and 5.6% in the Balearic and the Canary Islands, respectively, as opposed to 14.9% in Catalonia or 10.6% in the Valencian Community.

[11] Jiménez et al. (2023) also use the Balearic Islands as the comparison group to examine the effect of a travel subsidy policy implemented for residents in a DiD setting.

[12] This strategy is similar to that implemented in Belasen and Polachek (2009) to analyze hurricane effects on the economy. These authors consider potential neighbouring effects by dividing their sample into three main groups: (i) counties directly hit by the weather catastrophe, (ii) those that are close to hit areas and that could have experienced some weather distortions, and (iii) counties located further away that did not suffer any effect.

Table 1 Descriptive statistics of the variables

Time	Sample	Variable	Mean	SD	Min	Max
	Full sample	FOREIGN TOURISTS	102,833.3	1.7e+05	46	1,245,354
		HOTELS	109.9	147.9	9	908
		WORKERS	6846.3	80,44.8	68	48,002
Pre-eruption	La Palma	FOREIGN TOURISTS	1,234.3	1206.2	288	4370
		HOTELS	11.6	1.7	9	15
		WORKERS	257.1	143.3	173	569
	Potentially treated	FOREIGN TOURISTS	21,282.7	25,634.5	46	129,653
		HOTELS	49.5	32.5	14	152
		WORKERS	3533.0	2887.3	68	13,228
	Non treated	FOREIGN TOURISTS	90,975.6	1.6e+05	341	647,527
		HOTELS	151.5	177.1	11	734
		WORKERS	4885.0	7744.0	96	31,607
Eruption time	La Palma	FOREIGN TOURISTS	1474.5	537.3	1082	2269
		HOTELS	15.2	0.5	15	16
		WORKERS	429.2	80.3	359	545
	Potentially treated	FOREIGN TOURISTS	103,207.7	72,398.3	140	226,027
		HOTELS	91.5	56.1	15	192
		WORKERS	8274.8	5749.6	82	17,730
	Non treated	FOREIGN TOURISTS	172,632.9	2.0e+05	3869	613,619
		HOTELS	231.7	222.9	20	716
		WORKERS	8909.7	9909.3	228	30,872
Post-eruption	La Palma	FOREIGN TOURISTS	3634.0	1552.5	746	5905
		HOTELS	15.2	0.9	14	17
		WORKERS	527.3	82.3	375	602
	Potentially treated	FOREIGN TOURISTS	121,407.8	83,088.2	136	272,236
		HOTELS	99.6	59.9	17	211
		WORKERS	9252.3	6352.3	82	19,950
	Non treated	FOREIGN TOURISTS	337,223.4	3.7e+05	2613	1,245,354
		HOTELS	308.0	286.0	18	908
		WORKERS	14,284.6	14,957.1	230	48,002

eruption in La Palma than in the pre-treatment period. However, the figures for the potentially treated and nontreated groups are also greatly over their pre-treatment levels. The reason is that demand smoothly increased in all areas over the study period as the pandemic situation improved. Therefore, the identification of the effect of the volcano on La Palma and surrounding tourist zones (potentially treated) cannot be done based on descriptive statistics: A simple comparison of the change in outcomes in La Palma pre- and post-event would lead to myopic estimates. The overall positive trend calls for a model that estimates the volcano-induced gap in observed demand, supply and hospitality workers relative to a counterfactual of what would have happened in the absence of the eruption.

4 Empirical Strategy

4.1 Econometric Modelling

To answer our research questions, we compare the trajectories of FOREIGN TOURISTS, HOTELS and WORKERS (all expressed in natural logarithms) in La Palma (*Treated*) and the other potentially affected nearby islands (*Pot.treated*) to that of the tourist zones in the Balearic Islands *(Non-treated)* in the months immediately preceding and immediately following the event. To get causal estimates, we combine a difference-in-differences research design (DiD) that considers period and unit fixed effects with seemingly unrelated Regression (SUR). Since demand and supply are jointly determined, we allow for common time-varying unobserved shocks affecting the three variables of interest, implying that the three DiD equations are jointly estimated allowing for correlated error terms.[13] We estimate the following model:

$$
\begin{aligned}
\ln FOREIGNTOURISTS_{it} = \alpha^{T} + {\beta_1}^{T} LaPalma_i \times During_t + {\beta_2}^{T} LaPalma_i \\
\times Post.Eruption_t + {\delta_1}^{T} Pot.treated_i \times During_t \\
+ {\delta_2}^{T} Pot.treated_i \times Post.Eruption_t + {\mu_i}^{T} + {\tau_t}^{T} + {\varepsilon_{it}}^{T}
\end{aligned}
$$

$$
\begin{aligned}
\ln HOTELS_{it} = \alpha^{H} + {\beta_1}^{H} LaPalma_i \times During_t + {\beta_2}^{H} LaPalma_i \times Post.Eruption_t \\
+ {\delta_1}^{H} Pot.treated_i \times During_t + {\delta_2}^{H} Pot.treated_i \times Post.Eruption_t \\
+ {\mu_i}^{H} + {\tau_t}^{H} + {\varepsilon_{it}}^{H}
\end{aligned}
$$

$$
\begin{aligned}
\ln WORKERS_{it} = \alpha^{W} + {\beta_1}^{W} LaPalma_i \times During_t + {\beta_2}^{W} LaPalma_i \\
\times Post.Eruption_t + {\delta_1}^{W} Pot.treated_i \times During_t \\
+ {\delta_2}^{W} Pot.treated_i \times Post.Eruption_t + {\mu_i}^{W} + {\tau_t}^{W} + {\varepsilon_{it}}^{W}
\end{aligned} \tag{1}
$$

4.1.1 (1)

Where i indexes tourist zones ($i = 1, \dots, 12$), *LaPalma* is a dummy indicator for La Palma zone, *Pot.treated* is a dummy for the potentially treated zones, *During* indicates the time period when the volcano was erupting (September 2021–December 2021), *Post.Eruption* refers to the post-eruption period (January 2022–December 2022), t denotes time periods ($t = Sep.20, \dots, Dec.22$), μ_i are unit fixed effects capturing any time-invariant zone-specific unobservable characteristic like the endowment of natural amenities, τ_t are period (month-year) fixed effects gathering any common period-specific shocks (including seasonality) and ε_{it} is the error term.[14]

[13] We do not assume any structural relationship between the variables since the identification of such a model would require suitable exclusion restrictions that are not available.

[14] Because we allow for potential spillover effects within a DiD research design, the model in (1) to some extent resembles that of Lima and Barbosa (2019). These authors consider the treatment status of neighboring municipalities weighted by binary contiguity and the closest neighbor weighting matrixes. We discard the use of a spatial weighting matrix since we avail of a reduced number of cross-sectional units.

The three equations are jointly estimated by Generalized Least Squares, allowing the error terms to be correlated in a SUR framework (Zellner 1962). Although we could perform an equation-by-equation analysis, it is well known that there are important efficiency gains associated with joint estimation, particularly when the outcomes are likely to share common driving forces. In this way, our modelling strategy allows for common time-varying unobserved shocks affecting the three dependent variables other than the treatment effects of interest. We cluster standard errors at the tourist zone level to capture the within-unit dependence in observations due to arbitrary serial correlation in accordance with common practice (e.g., Bertrand et al. 2004).[15]

An alternative strategy could be to use the Synthetic Control Method (SCM; Abadie and Gardeazabal 2003) or synthetic difference-in-differences (SDID; Arkhangelsky et al. 2021). We exclude these approaches for three main reasons. First, the COVID-19 pandemic and the strict lockdown that took place in Spain between March and June 2020 produced an important break in the series. We thus have a short pre-treatment period to construct the synthetic treated units. Second, our interest in examining potential spillover effects on nearby islands and distinct effects during and post-eruption would require an expansion of the donor pool to tourist zones from the Spanish peninsula that are unlikely to be appropriate predictors of tourism dynamics in the islands. Third, we do not avail enough monthly predictors varying at the tourist zone level to construct the weights.

Given the peculiarities of our DiD design with two levels of treatment depending on the *exposure* to the risk (LaPalma and the group of potentially treated tourist zones) and two treatment periods after the event (during and post-eruption), Table A2 in the Online Appendix summarises the four main coefficients of interest for each equation that result from the double differences. The parameter β_1 measures the difference in outcomes between La Palma and the non-treated zones between during and pre-eruption. δ_1 captures the corresponding change between the potentially treated zones and the non-treated areas. Similarly, β_2 and δ_2 reflect the outcome change between La Palma and non-treated and between potentially treated and non-treated in the post-eruption period relative to the pre-eruption values.[16]

4.2 Parallel-Trend Assumption

The validity of our difference-in-differences strategy relies on the well-known parallel trend assumption. Prior to the empirical analysis, we tested whether treated and non-treated units follow parallel trends in the three outcomes of interest before the event. We ran SUR-type regressions for the pre-treatment period (September 2020–August 2021) considering a linear trend, an interaction between the trend and the dummy for La Palma, and unit fixed effects (Columns [1]–[3] in Table A4 in the Online Appendix). The interaction term is not significant in any of the three regressions, suggesting that FOREIGN TOURISTS,

[15] We use the *suregr* module developed by Kolev (2021). Auxiliary analyses using monthly data for the period January 2010–December 2019 point to serial correlation in the series. The Wooldridge autocorrelation test for panel data rejects the assumption of no first-order serial autocorrelation: $F(1,10)=210.91$, p-value <0.001 for foreign tourists; $F(1,10)=262.83$, p-value <0.001 for the number of hotels open; and $F(1,10)=2247.35$, p-value <0.001 for the number of workers.

[16] The specification does not include binary indicators for *Pot.treated*, *During* and *Post* because our model already includes year-month and tourist zone fixed effects. Note these three dummies are averages of the year-month and unit fixed effects. Nonetheless, Table A3 in the Supplementary Material presents the analogous results for Table A2 including them in the regression, and Table A6 presents the corresponding estimation results, which are the same.

HOTELS and WORKERS (in natural logarithms) follow parallel trends between La Palma and the rest before the shock. Online appendix Figures A1–A3 in the Appendix plot the time evolution of outcomes from a linear-trends model. These graphical diagnoses also point to the same conclusions as in Online appendix Table A4.

Although testing the statistical significance of the interaction between the treated unit and a time trend is a common way to test for the parallel trend assumption, some recent works have argued that it might have low power (Roth 2022). This might be more problematic when there is a relatively short pre-treatment period. Therefore, we perform a similar exercise using monthly panel data covering the period January 2010 to December 2019 for each of the twelve tourist zones. We estimated SUR-type regressions with interactions between the time trend and La Palma Island and between the time trend and potentially treated zones (Table A5 in the Online Appendix) together with monthly and zone fixed effects. This check provides additional support for the plausible fulfilment of the parallel trends assumption.[17]

4.3 Expected Effects and Potential Economic Mechanisms

In line with findings from previous works (Mazzocchi and Montini 2001; Rosselló et al. 2020), we expect tourism demand to have declined during the active phase of the volcano eruption, both in the directly affected area (La Palma, where the volcano is located), and plausibly also in the neighbouring potentially treated areas through a risk avoidance channel. From a microeconomic perspective, an individual's choice of a vacation destination is the result of a utility maximisation process that depends on preferences over hedonic characteristics of alternative destinations à la Lancaster (1966). Events that suppose a threat to visiting experience and personal safety are perceived as a deterioration in quality that likely rotates indifference curves, reducing choice probabilities at the individual level and, as a result, aggregate demand. In this sense, risk avoidance is a major factor in explaining tourists' travel destination choices (Karl 2018). Anticipatory feelings of exposure to risk induce people to adjust their choices (Caplin and Leahy 2001), particularly when the potential negative effects of taking the risk are more salient and even if their objective probability of occurrence is small (Bordalo et al. 2012). This is reinforced by media coverage that further contributes to deter tourism demand through increased risk perceptions (Besley et al. 2021). In this respect, related works have documented that sensationalist media reports about disasters deteriorate destination image and exacerbate tourism revenue losses (Pearlman and Melnik 2008; Walters et al. 2016).

The expected shrinkage in demand is likely to reflect on hotel supply and, in turn, on the number of workers hired (labour input). When demand becomes uncertain and in the presence of high fixed costs, service industries shrink their supply to avoid excess capacity. Like the adjustment in hospital beds (e.g., Gaynor and Anderson 1995), it is predicted that hospitality firms will also adapt their inventory due to the significant capital adjustment costs they incur (Butters 2020). Moreover, demand uncertainty might make some firms temporarily exit the market as predicted by Bloom (2009). Therefore, we expect that natural disasters that deter demand also alter accommodation supply, although potentially with some delay. The potential destruction of buildings and capital infrastructure (Cavallo et al.

[17] The only exception is nonetheless the number of hotels in La Palma, which exhibits a significant downward trend as compared to the rest. We examine the sensitivity of our findings to this in Sect. 5.2.

2010; Kim and Marcouiller 2015) could be other factors that contribute to drops in hospitality supply.

The derived demand for labour input is also expected to shrink following the eruption through decreased productivity (Park et al. 2016). It is well-known that hospitality labour is highly seasonal and adjusts to variations in demand (Alemayehu and Tveteraas 2020). The seasonality of hospitality labour markets is thus highly dependent on positive and negative shifts in tourism demand, with hirings and layoffs correlated with occupancy rates and expectations about future demand (Krakover 2000). Furthermore, natural disasters induce people to migrate (Boustan et al. 2012; 2020), increase the probability of working in the informal sector (Mendoza and Jara 2020), produce shifts in labour supply across sectors (Kirchberger 2017) and income reallocation effects within the wage distribution (Mendoza and Jara 2022). Recent evidence by Barattieri et al. (2023) show that, in Puerto Rico, the accommodation industry together with the scenic and sightseeing transportation sector are among the most affected in terms of employment destruction in the year that follows a hurricane.

Therefore, we expect β_1 and δ_1 (*during* eruption DiD estimands) to be negative in all the equations, with β_1 being comparatively greater (in absolute terms) than δ_1. This is because La Palma Island is likely to experience drops in demand due to risk avoidance and damage to infrastructure, facilities and the natural environment. In contrast, the areas potentially affected by the eruption but not directly hit by it are likely to experience only risk avoidance effects. From a temporal perspective, though, the signs of β_2 and δ_2(*post*-eruption DiD estimands) are unclear a priori. According to disaster recovery theories, we could expect three different scenarios.

First, the 'non recovery' hypothesis postulates that after being hit by a natural disaster, output will be temporarily lower than its pre-shock trajectory through the destruction of capital stock (Cavallo et al. 2010), displacement of workers (Boustan et al. 2012, 2020) and the decline in complementary business activity or reduced demand through travellers' risk avoidance (Park and Reisinger 2010). Some authors have documented persistent negative effects after natural shocks (Fingleton et al. 2012; McDermott et al. 2014). From this viewpoint, β_2 and δ_2 are predicted to have a negative sign.

A second possibility is the so-called 'recovery to the trend' hypothesis, which postulates that tourism outputs will rapidly go back to their pre-shock levels once the volcano has stopped erupting, especially in developed regions (Cheng and Zhang 2020; Lima and Barbosa 2019; Strobl 2011; Xiao 2011). If so, β_2 and δ_2 would be non-significantly different from zero.

Lastly, the 'build back better' hypothesis suggests that tourism outputs may even increase in the post-eruption period through demand surges associated with dark tourism (e.g., Biran et al. 2014; Rittichainuwat 2008) or the use of financial aid to improve public infrastructure and services, resembling some form of Schumpeterian creative destruction (Cuaresma et al. 2008; Leiter et al. 2009). For instance, disasters like hurricanes have been shown to boost damage-mitigating patents after the event (Noy and Strobl 2023). Under this scenario, we would expect positive estimates for β_2 and δ_2.

Table 2 Seemingly unrelated Difference-in-differences estimation results (SUR-DiD)

Variables	(1) Ln FOREIGN TOURISTS	(2) Ln HOTELS	(3) Ln WORKERS
La Palma × During	−0.942***	−0.266***	−0.385***
	(0.020)	(0.069)	(0.073)
La Palma × Post	−0.688***	−0.501***	−0.608***
	(0.068)	(0.078)	(0.098)
Pot.treated × During	0.322***	0.029	−0.252
	(0.107)	(0.120)	(0.154)
Pot.treated × Post	−0.125	−0.107	−0.584***
	(0.161)	(0.120)	(0.177)
Unit fixed effects	YES	YES	YES
Period fixed effects	YES	YES	YES
$\chi^2(1)$ test La Palma × During = La Palma × Post	21.2 [< 0.001]	108.5 [< 0.001]	63.37 [< 0.001]
$\chi^2(1)$ test Pot.treated × During = Pot.treated × Post	39.8 [< 0.001]	27.07 [< 0.001]	114.2 [< 0.001]
$\chi^2(2)$ test La Palma × During equal across equations	96.6 [0.001]		
$\chi^2(2)$ test La Palma × Post equal across equations	40.0 [< 0.001]		
$\chi^2(2)$ test Pot.treated × During equal across equations	53.0 [< 0.001]		
$\chi^2(2)$ test Pot.treated × Post equal across equations	90.2 [< 0.001]		
Observations	336	336	336
Number of tourist zones	12	12	12
Number of periods	28	28	28
R-squared	0.898	0.837	0.884
% Explained by DiD estimands	6.81	9.14	5.08
% Explained by unit FE	73.96	71.29	81.63
% Explained by period FE	19.23	19.57	13.29

Clustered standard errors at the unit-level in parentheses. *P*-values in brackets. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

5 Results

5.1 Main Findings

Table 2 and Fig. 6 present the SUR-DiD estimation results.[18] Since the four parameters of interest represent semi-elasticities, in Table 3, we follow Halvorsen and Palmquist (1980) and show the percentage change in the dependent variables to facilitate the interpretation.

[18] The Breusch-Pagan test confirms the existence of significant correlations between the error terms of the three equations ($${\chi }^{2}$$(3) = 918.79, *p*-value < 0.01), thus validating the use of the SUR methodology. Specifically, there is evidence of common unobserved factors simultaneously affecting the three outcomes, such as hotel prices and the prices of complement and substitute services, among other dimensions.

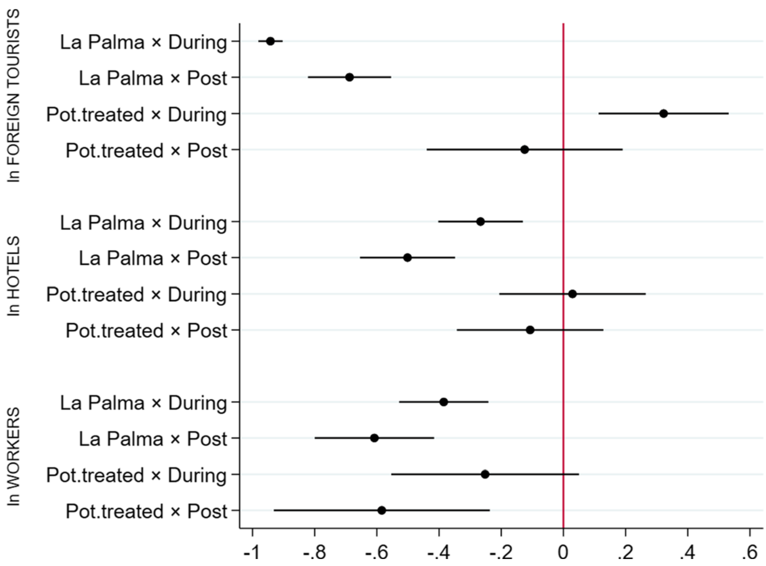

Fig. 6 Coefficient estimates and confidence intervals from SUR-DiD in Table 2

Table 3 Elasticities calculation from SUR-DiD estimates in Table 2

Variables	Coeff	(1) % Change FOREIGN TOURISTS	(2) % Change HOTELS	(3) % Change WORKERS
La Palma × During	β_1	−61.02%	−23.36%	−31.96%
La Palma × Post	β_2	−49.74%	−39.41%	−45.56%
Pot.treated × During	δ_1	37.99%		
Pot.treated × Post	δ_2			−44.23%

Only % change of statistically significant coefficients has been computed

A detailed decomposition of the DiD estimates for each equation is shown in the Online Appendix, Tables A7–A9.

We find the volcano has led to significant drops in all three outcomes in La Palma as compared to the control group. Specifically, the number of foreign tourists in the island decreased by 61% during the eruption and by 49.7% in the post-eruption period (i.e., the twelve-month window following the event). This finding is consistent with our expectations and also with previous results by Rosselló et al. (2020) and Mazzochi and Montini (2001). A Wald test confirms that these two coefficients are statistically different from each other ($\chi^2(1)=21.2$, p-value <0.001). This result indicates that the drop in hotel demand was particularly strong in the active phase of the eruption but persisted after the end of the eruption. Foreign tourism demand in La Palma has not rebounded during 2022, but it is exhibiting a slow-recovery trajectory. Although our analysis mainly focuses on the short-term effects, our estimates for the post-eruption period suggest it will take some time for the island to recover its pre-eruption international demand levels. The persistence of the demand decline is potentially due to two complementary reasons. First, the eruption might have caused direct damage to local amenities and capital infrastructure (Cavallo et al. 2010; Kim and Marcouiller 2015), which has reduced the attractiveness of the destination. Second, the rise in perceived hazard might have worsened the island's destination image (Wu and Shimizu 2020), deterring travellers from their intention to travel there due to risk aversion (Huan et al. 2004; Park and Reisinger 2010; Karl 2018).

We also document that the number of hotel establishments in La Palma declined by 23.4% during the eruption and by 39.4% in the post-eruption period. Wald tests indicate that the coefficients are statistically different between the during and post periods ($\chi^2(1)=108.5$, p-value <0.001). Aside from the potential destruction of and damage to the infrastructure of some hotels that forced them to close, this decline is compatible with adjustments in excess capacity. In line with Butters (2020), some hotels exit the market when faced with a negative demand shock to avoid costly unused capacity. Conversely to the case of demand, the effects on supply are stronger after the eruption than during the eruption and lower in magnitude. This likely reflects short-run supply rigidities that typically characterise the hotel industry (Chen and Chang 2012) and make most firms continue in the market despite the negative shift in demand. Our estimates thus suggest that the supply side rather slowly adjusts its inventory capacity to demand changes, partly due to contractual obligations.

As for the derived labour demand, the number of hotel workers decreased by 32% during the eruption and by 45.6% after it. This result falls in line with previous evidence from Boustan et al. (2020) and Barattieri et al. (2023) that shows that declines in local labour demand follow natural disasters. Under upward-sloping marginal cost functions, the negative demand shock and the associated uncertainty concerning its future evolution produce important revenue losses when the supply cannot instantaneously adjust (Tisdell 1963), which forces hotels to dismiss part of their labour force to reduce their variable costs, particularly employees with temporal contracts. Again, Wald tests indicated that the coefficients are statistically different between the during and post periods ($\chi^2(1)=63.37$, p-value <0.001).

If we compare the effects of the volcano on the three outcomes, it is clear that hotel supply presents more rigidities than demand. As expected, when faced with an exogenous shock, demand drops immediately, while supply (and, therefore, the derived labour demand) does not instantaneously adjust. Another explanation for this asymmetric evolution is that although international visitors declined, hotels could have partially compensated during the eruption through the arrival of humanitarian help and professionals (e.g., journalists, geologists, military) from Spain to battle the disaster, in line with Walters et al. (2015).

Regarding potential spillover effects in the other zones in the Canary Islands, the evidence is less clear. Contrary to our expectations, results for tourism demand indicate that during the eruption period, the nearby islands in the Canary archipelago experienced a 38% increase in the number of foreign visitors. This finding could potentially be explained by substitution effects between the islands. As previously discussed, changes in risk perceptions may modify destination choice probabilities towards less risky areas with a similar endowment of characteristics. This finding is consistent with prior research on the effect of increased risk on intraregional substitution patterns (e.g., Groizard et al. 2022). However, this effect appears to be only temporary, with no statistically significant difference in the post-eruption period. The volcano appears to have produced lasting effects only on directly hit areas. Regarding the supply side, no significant effects were detected. However, the potentially treated areas registered a 44.2% drop in the workforce hired in the post-eruption

Table 4 Seemingly unrelated Difference-in-differences estimation results (SUR-DiD) using total tourists

Variables	(1) Ln total TOURISTS	(2) Ln HOTELS	(3) Ln WORKERS
La Palma × During	−0.223***	−0.266***	−0.385***
	(0.061)	(0.069)	(0.073)
La Palma × Post	−0.597***	−0.501***	−0.608***
	(0.088)	(0.078)	(0.098)
Pot.treated × During	0.156	0.029	−0.252
	(0.141)	(0.120)	(0.154)
Pot.treated × Post	−0.255	−0.107	−0.584***
	(0.171)	(0.120)	(0.177)
Unit fixed effects	YES	YES	YES
Period fixed effects	YES	YES	YES
$\chi^2(1)$ test La Palma × During = La Palma × Post	157.4 [<0.001]	108.5 [<0.001]	63.37 [<0.001]
$\chi^2(1)$ test Pot.treated × During = Pot.treated × Post	124.5 [<0.001]	27.07 [<0.001]	114.2 [<0.001]
$\chi^2(2)$ test La Palma × During equal across equations	147.3 [<0.001]		
$\chi^2(2)$ test La Palma × Post equal across equations	1954.7 [<0.001]		
$\chi^2(2)$ test Pot.treated × During equal across equations	76.5 [<0.001]		
$\chi^2(2)$ test Pot.treated × Post equal across equations	54.8 [<0.001]		
Observations	336	336	336
Number of tourist zones	12	12	12
Number of periods	28	28	28
R-squared	0.911	0.838	0.884
% Explained by DiD estimands	5.15	9.14	5.08
% Explained by unit FE	72.63	71.29	81.63
% Explained by period FE	22.22	19.57	13.29

Clustered standard errors at the unit-level in parentheses. *P*-values in brackets. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

period. This negative spillover effect on labour demand is consistent with evidence presented by Belasen and Polachek (2009).

The independent variables in the SUR-DiD regressions explain around 90% of the variance of the dependent variable according to the individual R-squared measures. Nonetheless, this indicator should be interpreted with care under Generalized Least Squares estimation with high-dimensional two-way fixed effects. The bottom part of Table 2 presents a Shapley-type decomposition of the explained variance for each dependent variable (Israeli 2007). The DiD estimates (β_1, β_2, δ_1 and δ_2) explain around 7% of the explained variation in foreign tourism demand, the unit fixed effects explain 74% and the period fixed effects explain the remaining 19%. The contribution of each block of variables to the number of establishments and workers is slightly different. The DiD estimates explain approximately 9% of the variation in tourism supply but only 5% of the variation in the number of workers. The effects of unit and time fixed effects on establishments are similar to those for demand. However, the variation in workers is primarily explained by the unit fixed effects (81%).

To provide an overall estimate of the economic impact of the decline in tourist arrivals on the tourism industry, we conducted a simple back-of-the-envelope calculation. According to official statistics from the Instituto Canario de Estadística (ISTAC), the average per-capita expenditure for visitors staying at least one night in La Palma was €1,331.19 (USD 1,625.38) in the last quarter of 2019 and €1,386.31 (USD 1,692.68) considering the entire year.[19] Based on our model estimates, we project that the volcanic eruption resulted in revenue losses of about €63.8 million (USD 77.8 million) during the eruption period and €194.9 million (USD 238 million) during the post-eruption period.

5.2 Robustness Checks and Additional Analyses

We performed some robustness checks on our analysis. First, rather than considering only the international segment, we have re-estimated the model using the total number of tourists (including international, domestic and local tourists). The estimates are presented in Table 4. We document that (i) the effect of the volcano on total demand in La Palma is smaller in magnitude as compared to Table 2; (ii) the effect is greater in the post-eruption period (-25% and -81.8%, respectively), since the difference in the coefficient estimates is statistically significant ($\chi^2(1) = 157.4$, p-value < 0.001); and (iii) there is no evidence of spillover effects on potentially treated zones. These results are compatible with the fact that during the eruption, La Palma received an inflow of emergency staff (firefighters, police officers, health personnel) and journalists to battle the disaster and report on it (thus, counting as national tourists). The estimates for the number of hotel establishments and employees remain unchanged.

Second, we did the analysis again using data for tourist apartments, an alternative type of accommodation establishment. These data are also defined at the tourist zone level and come from the Tourist Apartment Occupancy Survey conducted by the Spanish National Statistics Institute. Summary statistics are reported in Table A10 in the Online Appendix. Importantly, for this type of accommodation, we have data for only seven tourist zones (Mallorca Island, La Palma, Fuerteventura, Gran Canaria, La Gomera, Lanzarote and Tenerife). Table 5 reports the estimation results. Overall, the impact of volcanic eruptions on both demand and supply in La Palma has been predominantly negative. Interestingly, the effect is more pronounced during the eruption phase than in the post period. The volcanic disturbance had a significant impact on demand and resulted in a slow recovery process. The number of available apartments and workers also decreased during the eruption phase, with a slightly lesser decline in the following period. However, there is no evidence of spillover effects on neighbouring islands. This result is similar to the findings by Belasen and Polachek (2009), who found no evidence of significant effects of a hurricane on counties that were close to the disaster epicentre but not directly hit by it.

[19] The average tourism expenditure variable is drawn from the Tourism Expenditure Survey and represents the average amount of money spent by international tourists during their stay. This variable includes all expenditures related to tourism activities, such as accommodation, food and beverage, entertainment, shopping and local transportation, but excludes transportation costs incurred to reach the destination. See Instituto Canario de Estadística (ISTAC) for further details. The year 2019 is chosen to avoid the impact of the COVID-19 pandemic on tourism expenditures The exchange rate used for the calculations is the rate of the European Central Bank (ECB) on 17 July 2023.

Table 5 Seemingly unrelated Difference-in-differences estimation results (SUR-DiD) using data for apartments rather than hotels

Variables	(1) Ln FOREIGN TOURISTS	(2) Ln APART	(3) Ln WORKERS
La Palma × During	−1.457***	−0.639***	−0.745***
	(0.144)	(0.082)	(0.107)
La Palma × Post	−1.092***	−0.560***	−0.670***
	(0.218)	(0.093)	(0.144)
Pot.treated × During	0.230	0.011	0.049
	(0.154)	(0.084)	(0.109)
Pot.treated × Post	−0.094	−0.209	−0.124
	(0.296)	(0.185)	(0.184)
Unit fixed effects	YES	YES	YES
Period fixed effects	YES	YES	YES
$\chi^2(1)$ test La Palma × During = La Palma × Post	17.6 [<0.001]	11.5 [<0.001]	1.90 [0.168]
$\chi^2(1)$ test Pot.treated × During = Pot.treated × Post	3.67 [0.055]	2.38 [0.123]	2.50 [0.113]
$\chi^2(2)$ test La Palma × During equal across equations	170.9 [<0.001]		
$\chi^2(2)$ test La Palma × Post equal across equations	16.1 [<0.001]		
$\chi^2(2)$ test Pot.treated × During equal across equations	11.3 [0.003]		
$\chi^2(2)$ test Pot.treated × Post equal across equations	1.70 [0.428]		
Observations	196	196	196
Number of tourist zones	7	7	7
Number of periods	28	28	28
R-squared	0.866	0.868	0.905
% explained by DiD estimands	13.19	12.66	10.40
% explained by unit FE	61.14	79.65	78.97
% explained by period FE	25.68	7.69	10.63

Clustered standard errors at the unit-level in parentheses. *P*-values in brackets. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Because of data availability limitations, only the tourist zones of Mallorca Island, La Palma, Fuerteventura, Gran Canaria, La Gomera, Lanzarote and Tenerife are considered

Third, we inspected the sensitivity of our results to violations of the parallel trend assumption. For this purpose, we used the methods recently proposed by Rambachan and Roth (2023); we calculated the value of the treatment effects assuming that the post-treatment violation of parallel trends is no more than some constant $\overline{M}$ larger than the maximum violation in the pre-treatment period. The results from this check for La Palma are presented in Online appendix Table A11 and visually shown in Online appendix Figures A4–A6 in the Appendix. We document that the estimates are robust up to $\overline{M} = 1$, which appears to be the breakdown value for a null effect; when the post-treatment violation of parallel trends is longer than the worst pre-treatment violation of parallel trends, the confidence interval for the average treatment effect for La Palma includes zero.

Finally, we conducted the following placebo exercises. By restricting the sample to the pre-treatment period (September 2020–August 2021), we generated a fake treatment starting in May 2021 (to have four 'treatment' periods). By considering only the pre-pandemic period of January 2010–December 2019 (to have a larger sample period), we generated a fake treatment starting in September 2018 and lasting until December 2019 (to mimic the same temporal structure). As expected, no significant effects in any of the three outcomes is detected (available upon request).

6 Conclusions

6.1 Summary of Findings

This paper has evaluated the short-term impacts of the La Palma volcano's eruption on the tourism industry in the Canary Islands. This region is a well-known sun and beach tourism destination whose economy is highly dependent on this sector. Using a difference-in-difference research design, we studied the impact of the eruption on international hotel demand, supply and the related labour market, both during and after the eruption. Our empirical strategy allowed for common unobserved shocks affecting the three outcomes using seemingly unrelated regression. We also investigated potential heterogeneous effects depending on both the temporal and geographical degree of exposure.

Our results clearly indicate La Palma suffered a drop in international tourism demand, both during (–61.0%) and after (–49.7%) the eruption. Hotel supply is found to have also declined as a response to the natural hazard. However, hotel supply exhibited comparatively more rigidities than demand; the decline in hotel supply was comparatively greater after the eruption period (–23.4%) than during the event (–39.4%). In a similar fashion, the number of hotel workers declined more during the eruption (–32.0%) than after it (–45.6%). In the case of hotels, there is evidence of spillover effects on the demand in nearby islands in the Canary archipelago during the eruption but not after it. This finding appears to reflect substitution patterns in destination choice across islands during the active phase of the volcano.

6.2 Implications

Given the high dependence of island economies like La Palma on the tourism sector (Seetanah 2011) and how this could hinder economic growth (Schubert et al. 2011), the documented decline in demand is predicted to produce negative effects on other related industries through intersectoral linkages (Figini and Patuelli 2022). The shift in tourism demand in La Palma Island not only affects related sectors in the islands but might also expand to other regions in mainland Spain through input–output trade balances, as shown by Carrascal-Incera et al. (2015).

The results of this study suggest that tourism demand and supply reactions to the shock have been asymmetric in La Palma, with hotel supply adjusting its overcapacity with some delay and tourism demand continuing below its pre-eruption trend in the post period. As a result, the island has not exhibited much short-term resilience, which offers important implications for policymaking. Institutions play an important role in the recovery from natural disasters by allocating public funds and financial aid to affected areas and firms. Since the Canary Islands are located in a volcanic area, the building of climate-resilient infrastructures is a priority. In this regard, the need for public investments to recover from physical damage offers the opportunity to improve the quality of the island as a tourist destination. As such, in line with disaster risk-reduction literature, rebuilding the island could be seen as an opportunity to 'build it back better'. Exogenous weather events normally produce short-term disturbances in the economy, but they could be followed by long-run economic gains (Guimaraes et al. 1993). As per Leiter et al. (2009) and Noy and Strobl (2023), the shock could be exploited as an opportunity to use national funding aids to invest in capital assets that increase tourism productivity and destination attractiveness. Government efficiency is predicted to play a key role here (Yang et al. 2022), with decisions on how to invest aid funding crucial for the destination to recover.

Given that the negative short-term effects are mostly demand driven, public authorities should also consider the need to develop promotional campaigns aimed at alleviating tourists' risk aversion (Amstrong and Ritchie 2008). Research has shown that sensationalist media reports about disasters hamper destination image (Pearlman and Melnik 2008; Walters et al. 2016), so efforts should be devoted to target tourists interested in dark tourism and in visiting hit areas (Biran et al. 2014; Rittichainuwat 2008). The use of social media, like Twitter, could be a valuable strategy to promote tourism recovery, as illustrated by Fukui and Ohe (2020).

From another viewpoint, our findings are informative about the short-term costs of natural disasters for tourism-led economies. To mitigate the vulnerability of disaster-prone tourist dependent areas, effective disaster planning and contingency management is needed (Hystad and Keller 2008; Prideaux 2004; Pyke et al. 2016). Although the documented effects in La Palma can hardly be directly extrapolated to other areas, they can nevertheless be useful for scholars attempting to quantify the expected costs of future natural disasters in locations at risk of similar extreme events. In this regard, the quantification of the losses of natural disasters might be relevant for increasing social and political awareness of the need for mitigation policies. Comprehensive natural hazard awareness strategies are compulsory to develop appropriate response strategies when needed (Méheux and Parker 2006).

6.3 Limitations and Avenues for Future Research

The paper has some limitations that we envisage as avenues for future research. First, we have taken tourist zones as the unit of analysis for data availability reasons. If possible, future studies could use more granular data at the municipality or zip code level to investigate heterogeneous responses depending on regional characteristics. Second, we have focused on the short-term responses of the industry to the volcano. The study of the long-term recovery trajectories followed by tourism demand and supply could complement the findings reported in this paper.

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Declarations

Conflict of interest All authors have no conflicts of interest.

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