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The effect of natural disasters on tourism demand, supply and labour markets: Evidence from La Palma volcano eruption

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The effect of natural disasters on tourism demand, supply and labour markets: Evidence from La Palma volcano eruption

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Abstract:

This paper studies the short-term impact of a volcano eruption on tourism 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 at the touristic zone level, we use Seemingly-Unrelated Difference-in-Differences (SUR-DiD) to identify the distinct responses of these three outcomes during and post eruption. Potential spillover effects on nearby islands are also examined. We find that, in La Palma Island, the volcano produced significant but asymmetrical drops in international demand, number of hotels and hospitality workers both during and after the eruption.

Keywords: *natural disasters; tourism-led economy; resilience; recovery from disaster*

JEL classification numbers: *Q50, Q54, Z30.*

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NON-TECHNICAL SUMMARY

Climate change has resulted in an increased frequency and harshness of natural disasters, with considerable economic damages to the affected areas. Small economies, especially those characterized by a low variety of economic activities, are predicted to suffer the most from catastrophic events.

On these premises, our paper studies the short-term effect of *Cumbre Vieja* volcano eruption, located in La Palma Island (Spain), on the local tourism-led economy. We focus on three key dimensions: tourism demand, tourism supply and the related labour market.

We use a monthly panel dataset covering the entire Canary Archipelago for the period September 2020 and July 2022. To give our estimates a causal interpretation, we combine a difference-in-differences research design with Seemingly Unrelated Regression. This identification strategy allows for common unobserved shocks affecting the three related outcomes. An interesting feature of our work concerns the model specification, which is slightly different from the standard difference-in-differences setting. In fact, we consider two levels of treatment depending on the exposure to the risk (La Palma and the group of Potentially Treated islands) and two treatment periods after the event (during and post-eruption). This specification allows us to inspect the existence of spillover effects on nearby islands as well as the heterogeneity in the effects *during* and *after* the eruption.

We find that, in La Palma Island, the volcano produced significant but asymmetrical drops in international demand, number of hotels and hospitality workers both during and after the eruption. Our findings are informative about the short-term costs of natural disasters, especially for tourism-led economies and offer relevant policy implications. In this regard, the quantification of the losses of natural disasters might be relevant for increasing the social and political awareness about the need for climate-change mitigation policies.

1. INTRODUCTION

Natural disasters have become an ever-frequent occurrence due to climate change. Hurricanes, earthquakes, floods, or volcano eruptions represent an important threat for human societies and economic systems. A long body of research has shown that natural disasters produce important contemporaneous and middle term losses in economic growth for affected areas (Cavallo et al., 2010; Strobl, 2011), especially among low-income economies (McDermott et al., 2014). Apart from capital destruction and the corresponding slowdown in production, natural disasters induce people to migrate (Boustan et al., 2012; 2020), which therefore compromises recovery possibilities. In this regard, countries with higher income and educational attainment and stronger financial systems recover faster and exhibit greater resilience (Kahn, 2005; Toya & Skidmore, 2007). In the long-run, evidence on the impacts of disasters on economic growth is more unconclusive as the literature detects both long-lasting consequences on income (Karbownik & Wray, 2019) and children's education (Deuchert & Felfe, 2015), non-significant effects once other factors are controlled for (Cavallo et al., 2013), or heterogeneous recovery trajectories depending on the case study considered (Barone & Mocetti, 2014). Beyond economic effects, natural disasters also produce changes in social trust (Toya & Skidmore, 2014), drops in happiness (Rehdanz et al., 2015) and induce people to become more risk-averse (Cameron & Shah, 2015).

The goal of this paper is to evaluate the short-term effects of the eruption of *Cumbre Vieja* volcano occurred in 2021, located in La Palma Island, on the local economy, focusing on three key dimensions: tourism demand, tourism supply and the related labor market. La Palma is an island in the Canary Archipelago (Spain), whose 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 19th September 2021, *Cumbre Vieja* volcano started on eruption until middle December. During the 85 days it was erupting, the volcano emitted between 6,00 and 11,000 daily tons of sulfuric dioxide. According to the Volcanological Institute of the Canary Islands, the emissions of sulfuric dioxide to the atmosphere were equivalent as the total emissions of the 28 European countries in 2019 (El Mundo, 2021). Although no casualties have been reported, the eruption caused important damages worth 842 million euros and high environmental pollution (EuropaPress, 2021).

We exploit the exogenous occurrence of the natural shock to study the vulnerability and short-term resilience of the tourism sector, both *during* and *post* eruption. Moreover, we allow for potential heterogeneous effects across areas depending on the degree of exposure to the risk. Specifically, this work aims to answer the following research questions: what have been the impacts of the volcano eruption on hotel demand and supply and the hospitality labor market during and post-eruption? Are there spillover effects on nearby islands? Has the shock affected demand and supply symmetrically?

For this purpose, we use a monthly panel dataset on the number of foreign tourists, hotel establishments opened and hotel employees between September 2020 and July 2022 in 8 touristic zones in the Canary Islands. Our identification strategy combines a difference-in-differences (DiD) research design with Seemingly Unrelated Regression (SUR) that allows for common unobserved shocks affecting the three outcomes. Additionally, our empirical analysis considers potential *spillover* effects on the geographically linked islands of La Gomera and Tenerife (which belong to the same province of Santa Cruz de Tenerife), treating the far more distant islands of Lanzarote, Fuerteventura and Gran Canaria (belonging to Las Palmas province) as pure controls.

The analysis of how the volcano eruption disturbed the tourism industry and the hospitality labor market is economically relevant for different reasons. Firstly, tourism has been proved to be an important driver of long-run economic growth for local areas (Bronzini et al., 2022; Faber & Gaubert, 2019; Schubert et al., 2011), particularly for island economies specialized in sun and beach tourism (Seetanah, 2011). Accordingly, the resilience of the tourism market to the shock is not only relevant for the industry itself but for the whole economy through the corresponding multiplier effects on other related sectors (Figini & Patuelli, 2022; Xu et al., 2020; Zhang et al., 2007) and the positive link between tourism and international trade (Santana-Gallego et al., 2011). Secondly, empirical studies on regional resilience following macroeconomic shocks or natural disasters typically find that economic diversification attenuates the short-term impact and persistence of the shock (Coulson et al., 2020). Since the Canary Islands are highly specialized in the tourism sector, the economic effects of the volcano eruption for the region are predicted to be substantial. In this vein, there is some debate about whether islands lag behind their inland counterparts within the same country due to their remoteness (Del Gato & Mastinu, 2018). Thirdly, the economic effects of volcano eruption on the tourism industry are particularly relevant since previous works have shown that volcanic eruptions typically cause the most negative impacts on tourism (Rosselló et al., 2020). Overall, it seems relevant for policy makers to improve their understanding of how disasters affect the tourism industry and how long it takes to bounce back. In this regard, the results could be highly informative for similar tourism-dependent islands in the advent of alike extreme events in the near future.

The paper adds to a large literature on the economic effects of natural disasters on local economies (Lima & Barbosa, 2019: Kim & Marcouiller, 2015; Xiao, 2011). We expand existing knowledge about the impacts of natural disasters on tourism demand (Huang & Min, 2002; Mazzocchi & Montini, 2001; Rosselló et al., 2020), tourism supply (Brown et al., 2021; Chen et al., 2021) and labor markets (Belasen & Polachek, 2008; 2009; Ewing et al., 2009; Fouzia et al., 2020; Mendoza & Jara, 2022; Rodríguez-Oreggia, 2013) by jointly examining the distinct temporal trajectories followed by tourism demand and supply and the hospitality labor market *during* and *post* the volcano eruption. In doing so, we can assess potential asymmetric reactions across regions, over time and among outcomes.

The rest of the paper is organized as follows. In section 2 we present our case study. In section 3, we describe the dataset and report some descriptive statistics. The empirical strategy is described in Section 4. Section 5 shows and discusses the estimation results. The last section summarizes the main findings of the paper and concludes with some policy implications.

2. CASE STUDY: LA PALMA VOLCANO ERUPTION

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.[1] Figure 1 maps the geographic position of each of the islands. The archipelago has 2.2 million inhabitants and 7,4447 square kilometers. It has a volcanic origin and together with Cabo Verde, Madeira, Azores and the wild islands composed the Macaronesia region, a group of archipelagos in the Atlantic Ocean.

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

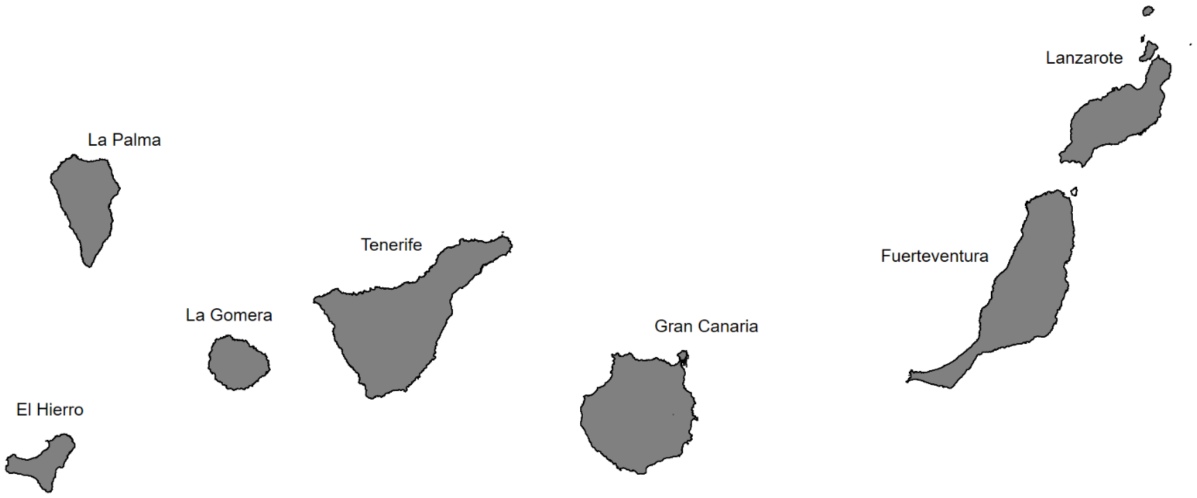

Figure 1. The Canary archipelago.

The region is highly specialized in tourism services. Its all-year round good weather conditions and thermal comfort, make it an attractive destination (Carrillo et al., 2022), particularly for the sun & beach tourism segment. The region annually receives around 10 million tourists, out of which 75% are foreign visitors (INE, 2022). In 2019, the tourism industry represented around 40% of its total employment and 35% of the regional GDP according to EXCELTUR (2019).

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 back to 19 September 2021, when *Cumbra Vieja* volcano (located in the municipality of El Paso, in the central-western part of La Palma Island) started on eruption. During the 85 days it was active, around 7,000 people were evacuated, 73.8 kilometres of roads were buried by lava and around 3,000 buildings were destroyed (El País, 2021). Moreover, about 2,300 people lost their houses and had to stay with friends or relatives. The overall losses are estimated to be around 842 million euros. The eruption received great attention and coverage by both Spanish and international media like BBC or The Wall Street Journal. The airport of La Palma (located in the eastern coast of the island) was nevertheless opened during 90% of the time the volcano was erupting and 74% of the scheduled flights between middle September and middle December were taken (AENA, 2021). On 13 December, the volcano finally stopped erupting.

3. DATA

We use official data about the monthly number of foreign visitors lodged at hotels (FOREIGN TOURISTS), the number of hotel establishments (HOTELS) and hotel workers (WORKERS) during the period September 2020-July 2022, in the Canary Islands. Although peer-to-peer accommodations (e.g., Airbnb) and private apartments 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).

Because of the break in the series caused by COVID-19 pandemic in 2020 and the associated lockdown measures implemented in Spain, we only consider one year before the volcano eruption. This choice is aimed at preventing the confounding effect of the pandemic in the pre--eruption period. The data is drawn from the Hotel Occupancy Survey conducted by the Spanish National Statistics Institute (INE) at the tourist zone level. The tourist zone is a regional aggregation set by INE that refers to a set of municipalities characterized by a high tourism demand. In the case of the Canary Islands, INE defines the following 8 tourist zones: Fuerteventura, Gran Canaria, South of Gran Canaria, La Gomera, La Palma, Lanzarote, Tenerife and South of Tenerife. That is, the two main islands of Gran Canaria and Tenerife are split into two distinct tourist zones whereas each of the other islands (except El Hierro) are considered as single tourist zones. Importantly, in the case of the Canary Islands, all the municipalities are assigned to one of the touristic zones so that the eight zones considered gather all the municipalities in the islands. A list of the municipalities in each zone is presented in Appendix, Table A1.

La Palma is the island where the volcano *Cumbra Vieja* is located. Therefore, La Palma is the *treated* unit in our empirical setting. According to the extant literature, the volcanic eruptions have a negative impact on ecosystems near the volcano, with detrimental effects on the vegetation cover, quality of lands and therefore the quality of living of animals (Filonchyk et al., 2022). During the eruption period, a large column of smoke and ashes (mostly S02) moved to the atmosphere and towards the Iberian Peninsula, potentially affecting the nearby islands of La Gomera and Tenerife. Apart from their geographical proximity, these islands belong to the same province 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 two zones of Tenerife and the one in La Gomera are considered as a potentially treated group (*Pot.treated*).

Since the islands of Gran Canaria, Fuerteventura and Lanzarote are located further away with respect to La Palma (and they also belong to another administrative province), they are less likely to be affected by the volcano eruption. Consequently, the two zones in Gran Canaria, Lanzarote and Fuerteventura constitute the *non-treated* (control) group. This strategy is similar to that implemented in Belasen and Polachek (2009) to analyze hurricane effects on the economy. These authors consider potential neighboring effects by dividing their sample into three main groups: counties directly hit by the weather catastrophe, those that are close to hit areas and that could have experienced some weather distortions, and counties located further away that did not suffer any effect. Figure 2 illustrates the composition of the treated (La Palma), potentially treated (Tenerife, South of Tenerife and La Gomera) and non-treated (Gran Canaria, South of Gran Canaria, Fuerteventura and Lanzarote) groups.

Figure 2. Treated (La Palma), potentially treated (Tenerife, South of Tenerife and La Gomera) and non-treated areas (Gran Canaria, South of Gran Canaria, Fuerteventura and Lanzarote).

An alternative strategy could be the consideration of other touristic zones in Spain (belonging to other administrative regions) as the control group. However, the appropriate identification of the eruption causal effects 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. Given the geographical remoteness of the Canary archipelago, its climate and natural amenities substantially differ from those of the rest of Spain, also exhibiting distinct seasonality patterns.[2] For this reason, we opted for a research design that considers a control group composed of plausibly non-treated areas belonging to the same region. This choice ensures a higher overlap in terms of destination image, attractiveness, and institutional environment. Even if the control group would turn out to be affected by the shock, the DiD estimand will still inform about the relative change post-eruption in demand, supply and labor demand between treated and non-treated areas.[3]

The volcano erupted from September 19th to December 13th, 2021. We consider the period between September 2020 and August 2021 as the pre-treatment period. Since the effects of the volcano on the tourism 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-July 2022, denoted by *Post*).

Table 1 presents descriptive statistics of the three variables of interest, disaggregated by group (La Palma, potentially treated and non-treated) and period (pre-, during and post- eruption). Hotels in La Palma hosted around 1,234 foreign tourists per month, on average, during the pre-treatment year, with around 12 hotels establishments and 257 workers. The corresponding figures for the potentially treated and the non-treated groups are notably larger given their greater size, although quite similar between them. Strikingly, the number of foreign tourists, hotels opened, and workers employed are larger during and post eruption in La Palma than in the pre-treatment period. However, note also that the figures for the potentially treated and nontreated groups are also greatly over their pre-treatment levels. The reason is that demand has smoothly increased in all areas over the study period as the pandemic situation has improved. Therefore, the identification of the effect of the volcano on La Palma and surrounding touristic 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 is able to estimate 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.

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[2] Duro (2016) shows that the Canary Islands stand among the least seasonal Spanish regions.

[3] This is similar to other works that use DiD research designs to identify the distinct effects of different policy interventions on COVID-19 cases (e.g., Cho, 2020) or political ideology on economic activity (Prieto-Rodríguez et al., 2022) among countries/states before and after the onset of COVID-19.

Table 1. Descriptive statistics of the variables

		Mean	SD	Min	Max
All sample (obs=184)	FOREIGN TOURISTS	64,148.27	71,439.04	288	253,860
	HOTELS	70.52	52.88	9	205
	WORKERS	6,037.74	5,283.09	173	19,401
La Palma pre-eruption (obs=12)	FOREIGN TOURISTS	1,234.33	1,206.18	288	4,370
	HOTELS	11.67	1.77	9	15
	WORKERS	257.17	143.29	173	569
Potentially treated pre-eruption (obs=36)	FOREIGN TOURISTS	25,129.08	29,511.716	413	127,830
	HOTELS	55.69	36.278	14	152
	WORKERS	4,476.64	3,521.545	343	13,326
Non-treated pre-eruption (obs=48)	FOREIGN TOURISTS	23,590.44	22,993.93	2,325	92,438
	HOTELS	52.73	29.30	17	135
	WORKERS	3,695.83	1,992.45	836	9,818
La Palma during eruption (obs=4)	FOREIGN TOURISTS	1,463.00	543.781	1,082	2,269
	HOTELS	15.25	0.500	15	16
	WORKERS	429.25	80.351	359	545
Potentially treated during eruption (obs=12)	FOREIGN TOURISTS	121,968.17	91,024.76	2,517	222,662
	HOTELS	105.08	71.92	15	192
	WORKERS	10,405.75	7,546.71	373	17,746
Non-treated during eruption (obs=16)	FOREIGN TOURISTS	112,939.81	35,697.457	51,935	166,496
	HOTELS	97.56	35.866	59	158
	WORKERS	8,676.38	2,194.443	5,233	11,548
La Palma post eruption (obs=7)	FOREIGN TOURISTS	2,761.14	1,300.64	746	4,181
	HOTELS	15.29	0.95	14	17
	WORKERS	481.29	80.99	375	585
Potentially treated post eruption (obs=21)	FOREIGN TOURISTS	142,820.95	1.04e+05	2,074	253,860
	HOTELS	116.24	77.31	16	205
	WORKERS	11,429.14	8,123.84	370	19,401
Non-treated post eruption (obs=28)	FOREIGN TOURISTS	123,443.07	29,543.70	61,684	171,825
	HOTELS	102.46	34.82	67	162
	WORKERS	9,303.93	2,149.74	6,140	12,436

4. EMPIRICAL STRATEGY

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 rest of touristic zones in the Islands *(Non-treated)* in the months immediately preceding and immediately following the event. In such a way, we distinguish three groups of touristic zones depending on their degree of exposure to the volcano. 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 the variables of interest, implying that the three DiD equations are jointly estimated allowing for correlated error terms.[4] We estimate the following model:

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

where *i* indexes touristic zones ($i = 1, \dots, 8$), *LaPalma* is a dummy indicator for the LaPalma, *Pot.treated* is a dummy for potentially treated zones (La Gomera, Tenerife and South of Tenerife), *During* indicates the time period when the volcano was erupting (September 2021-December 2021), *Post.Eruption* refers to the post-eruption period (January 2022-July 2022), *t* denotes time periods ($t = Sep.20, \dots, Jul.22$), 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.

The three equations are jointly estimated by Generalized Least Squares allowing the error terms to be correlated in a Seemingly-Unrelated Regression (SUR) framework (Zellner, 1962). Although we could perform an equation-by-equation analysis, it is well-known there are important efficiency gains associated with the 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 touristic zone level to capture the

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

within-unit dependence in observations (autocorrelation) following common practice (e.g., Bertrand et al., 2004).[5]

Because we allow for potential spillover effects within a DiD research design, the model resembles to some extent that by 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.

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 islands) and two treatment periods after the event (during and post-eruption), Table A2 in Appendix summarizes 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, respectively, in the post eruption period relative to the pre-eruption values.[6]

To interpret these parameters in a causal sense, we test whether treated and non-treated units follow parallel trends in the three outcomes of interest before the event. To this end, we run 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 2). The interaction term is not significant in none of the three regressions, suggesting that FOREIGN TOURISTS, HOTELS and WORKERS (in natural logarithms) follow parallel trends between La Palma and the rest before the shock.[7] Monthly variations due to seasonality and level differences in outcomes will be captured in the model by the period and unit fixed effects so that the three variables in La Palma and the rest of

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[5] We use the *suregr* module developed by Kolev (2021).

[6] The specification does not include binary indicators for *Pot.treated*, *During* and *Post* because our model already includes year-month and touristic zone fixed effects. Note these three dummies are averages of the year-month and unit fixed effects. Nonetheless, Table A3 in Supplementary Material presents the analogous of Table A2 including them in the regression and Table A4 the corresponding estimation results, which are exactly the same.

[7] 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, although some recent works argue that it might have low power (Roth, 2022). The dependent variables are specified in logs since our aim is to compute the elasticities of the three outcomes to the event.

touristic zones are expected to have moved in parallel in the absence of the volcano eruption. We perform the same exercise for each of the following subsample combinations: La Palma versus non-treated only (Columns (4)-(6) in Table 2), potentially treated versus non-treated only (Columns (1)-(3) in Table 3), and La Palma and potentially treated (province of Santa Cruz de Tenerife) versus non-treated (Columns (4)-(6) in Table 3). According to these checks, the three variables follow parallel trends in the three groups of comparison. Graphical diagnoses after a linear-trend adjustment also point to the same conclusions (Figures A1-A3 in Appendix).[8]

In line with previous works (Mazzocchi & Montini, 2001; Rosselló et al., 2020), we expect tourism demand to have declined during the time the volcano was erupting in La Palma and plausibly also in the potentially treated areas through a risk avoidance mechanism (e.g., Karl, 2018). As a consequence of this demand shrinking, the hotel supply as well as the number of hired workers are also predicted to have reduced. The decline in demand leads to adjustments in supply through revenue losses (Brown et al., 2021) and in derived demand for labor input through decreased productivity (Park et al., 2016). We therefore expect βs and δs to be negative in all the equations, with β_1s and δ_1s being relatively greater (in absolute terms) than β_2s and $\delta_2 s$. That is due to the greater degree of exposure to risk in La Palma as compared with potentially treated areas. Moreover, we expect δs to be smaller (in absolute terms) than βs, meaning that the impacts are predicted to be greater during than after the eruption.

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[8] The Figures in Appendix plot the time evolution of outcomes for treated and control units on the left and the predictions from a DiD model expanded with interactions between the period and treatment indicator on the right.

Table 2. Check for parallel trend assumption between La Palma and rest (Columns (1)-(3)) and La Palma and non-treated only (Columns (4)-(6))

Variables	(1) Ln FOREIGN TOURISTS	(2) Ln HOTELS	(3) Ln WORKERS	(4) Ln FOREIGN TOURISTS	(5) Ln HOTELS	(6) Ln WORKERS
Time trend	0.026***	0.035***	0.128***	0.037***	0.046***	0.141***
	(0.007)	(0.011)	(0.016)	(0.010)	(0.016)	(0.024)
La Palma x Time trend	0.003	0.049	0.068	-0.008	0.038	0.055
	(0.021)	(0.031)	(0.046)	(0.023)	(0.037)	(0.054)
Constant	3.311***	7.689***	8.950***	3.241***	7.620***	8.865***
	(0.083)	(0.123)	(0.183)	(0.099)	(0.156)	(0.227)
Treated	**La Palma**	**La Palma**	**La Palma**	**La Palma**	**La Palma**	**La Palma**
Controls	**Pot.treated+ non-treated**	**Pot.treated+ non-treated**	**Pot.treated+ non-treated**	**Non-treated**	**Non-treated**	**Non-treated**
Units	8	8	8	5	5	5
Time periods	12	12	12	12	12	12
Observations	96	96	96	60	60	60
R-squared	0.903	0.923	0.884	0.885	0.889	0.840

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

Table 3. Check for parallel trend assumption between La Palma and rest (Columns (1)-(3)) and La Palma and non-treated only (Columns (4)-(6))

Variables	(1) Ln FOREIGN TOURISTS	(2) Ln HOTELS	(3) Ln WORKERS	(4) Ln FOREIGN TOURISTS	(5) Ln HOTELS	(6) Ln WORKERS
Time trend	0.037***	0.046***	0.141***	0.037***	0.046***	0.141***
	(0.010)	(0.015)	(0.022)	(0.010)	(0.015)	(0.022)
Pot.treated x Time trend	-0.025	-0.025	-0.031			
	(0.016)	(0.022)	(0.034)			
Tenerife province x Time trend				-0.021	-0.009	-0.009
				(0.014)	(0.021)	(0.031)
Constant	3.241***	7.620***	8.865***	3.241***	7.620***	8.865***
	(0.096)	(0.139)	(0.212)	(0.091)	(0.139)	(0.207)
Treated	**Pot.treated**	**Pot.treated**	**Pot.treated**	**La Palma+ pot.treated**	**La Palma+ pot.treated**	**La Palma+ pot.treated**
Controls	**Non-treated**	**Non-treated**	**Non-treated**	**Non-trested**	**Non-trested**	**Non-trested**
Units	4	4	4	8	8	8
Time periods	12	12	12	12	12	12
Observations	84	84	84	96	96	96
R-squared	0.855	0.875	0.825	0.905	0.922	0.881

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

The trajectories followed by the three variables from January 2022 afterwards are unclear a priori. We could expect three different scenarios. Firstly, 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, displacement of workers, the decline in complementary business activity or reduced demand through travelers' risk avoidance. In this regard, some authors have documented persistent negative effects after natural shocks (Fingleton et al., 2012; McDermott et al., 2014). From this viewpoint, both β_1 and δ_1 are predicted to have negative sign.

A second possibility is the so called "recovery to the trend", according to which tourism output will rapidly go back to their pre-shock levels once the volcano stopped erupting, especially in developed regions (Lima & Barbosa, 2019; Cheng & Zhang, 2020; Strobl, 2011; Xiao, 2011). Accordingly, β_1 and δ_1 should be non-significantly different from zero in case of an immediate recovery, since that would mean there are no differences with respect to the pre-eruption trend.

Lastly, the "build back better", scenario postulates that the tourism output might even increase in the post-eruption period through demand surges associated with dark tourism travelling (e.g., Biran et al., 2014) or the use of financial aid to improve public infrastructure and services as some type of Schumpeterian creative destruction (Cuaresma et al., 2008; Leiter et al., 2009). If so, we would get positive estimates for β_1 and δ_1.

5. RESULTS

Table 4 shows the SUR-DiD estimation results. Since the four parameters of interest are semi-elasticities, in Table 5 we present the percentage change in the dependent variables following Halvorsen and Palmquist (1980) to facilitate the interpretation.

We find the volcano has produced a significant drop in all the three outcomes in La Palma as compared to the controls. Specifically, the number of foreign tourists in the island decreased by 76.7% during the *eruption* and by 64.5% in *the post eruption* period (i.e. the seven-month window following the event). This finding is consistent with our expectations and also 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 (chi2(1)=129.9, p-value<0.001). This result indicates that the drop in tourism demand persisted also after the end of the eruption. Foreign tourism demand in La Palma has not rebounded back to pre-event levels, exhibiting a slow-recovery trajectory following the end of the eruption. Although our analysis mainly focuses on the short-term effects, our estimates suggest it will take some time for the island to recover their pre-eruption international demand levels. This is potentially explained by both the destruction of local amenities and capital infrastructure and the worsening of the island's destination image that deters travelling there through a risk aversion channel (Karl, 2018).

We find that the number of hotel establishments in La Palma declined by 34.8% during the eruption and by 38.1% in the post period. Conversely to the case of tourism demand, the effects of the eruption on supply are stronger *after* than *during* the eruption. As for the derived labor demand, the number of hotel workers decreased by 30.6% during the eruption and by 27.7% after it. Again, Wald tests indicate that the coefficients for hotels and workers are statistically different between during and post periods (chi2(1)=33.00, p-value<0.001 and chi2(1)=15.33, p-value<0.001, respectively). As demand drops and some hotels are closed, the decline in labor productivity probably causes some workforce reduction.

If we compare the volcano effects on the three outcomes, tourism supply presents more rigidities than demand. As expected, faced with an exogenous shock, demand drops immediately, while supply (and therefore the derived labour demand) does not instantaneously adjust. The likely excess of supply during the eruption period induced an adjustment in the post-eruption period and a corresponding loss of employment in the sector. Until international demand does not resume, hotel supply and the associated number of hospitality workers are expected to lie below their pre-shock trends. Another explanation for this asymmetric evolution is that although international visitors declined, hotels could have partially compensated it through the arrival of humanitarian help and professionals (e.g., journalists, geologists, military) from Spain to battle the disaster.

Concerning potential *spillover effects* on the nearby islands, there is no evidence of significant effects of the volcano on the touristic zones in La Gomera and Tenerife (*Pot.treated* group), neither during nor post eruption. Our results suggest that close and distant islands to La Palma have not behaved differently in terms of foreign tourism demand, hotel supply and number of hospitality workers during and after the volcano eruption. Therefore, the volcano seems to have produced local effects only. This result is in line with the work by Belasen and Polachek (2009), who found no evidence of significant effects of a hurricane on counties close to the disaster epicenter but not directly hit by it.[9]

The Breusch-Pagan test confirms the existence of significant correlations between the error terms of the three equations (chi(2)=319.34, p-value<0.01), thus validating the use of the SUR methodology. In particular, there is evidence of common unobserved factors affecting the three outcomes simultaneously like hotel prices and the prices of complement and substitute services, among other dimensions.

Table 4. Seemingly unrelated Difference-in-differences estimation results (SUR-DiD)

Variables	(1) Ln FOREIGN TOURISTS	(2) Ln HOTELS	(3) Ln WORKERS
La Palma × During	-1.457***	-0.426***	-0.365***
	(0.090)	(0.061)	(0.050)
La Palma × Post	-1.037***	-0.481***	-0.325***
	(0.123)	(0.070)	(0.059)
Pot.treated × During	-0.306*	-0.235	-0.350
	(0.180)	(0.221)	(0.242)
Pot.treated × Post	-0.328	-0.174	-0.358
	(0.252)	(0.209)	(0.268)
Constant	8.966***	3.590***	7.983***
	(0.111)	(0.024)	(0.043)
Corr ($\varepsilon_{it}{}^{T}$, $\varepsilon_{it}{}^{H}$)		0.634	
Corr ($\varepsilon_{it}{}^{T}$, $\varepsilon_{it}{}^{W}$)		0.754	
Corr ($\varepsilon_{it}{}^{H}$, $\varepsilon_{it}{}^{W}$)		0.874	
Unit fixed effects	YES	YES	YES
Period fixed effects	YES	YES	YES
Observations	184	184	184
R-squared	0.974	0.967	0.980

Note: Clustered standard errors at the unit-level in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 5. Elasticities calculation from SUR-DiD estimates in Table 4

Variables	Coeff.	(1) % Change FOREIGN TOURISTS	(2) % Change HOTELS	(3) % Change WORKERS
La Palma × During	β_1	-76.70%	-34.79%	-30.58%
La Palma × Post	β_2	-64.55%	-38.18%	-27.75%

Note: Only % change of statistically significant coefficients has been computed.

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[9] It is important to indicate that the DiD estimands for the potentially treated regions (δ_1 and δ_2) become statistically significant at 95% confidence level when using default (non-clustered) standard errors. Abadie et al. (2022) recommend clustering for treatment effect estimation when there is potential treatment effect heterogeneity within clusters.

The model fit of the SUR-DiD is pretty good 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. Table A8 in Appendix presents a Shapley-type decomposition of the explained variance for each dependent variable (Israeli, 2007). The DiD estimands (β_1, β_2, δ_1 and δ_2) explain around 10% of the explained variation in foreign tourism demand, the unit fixed effects the 62% and the period fixed effects the remaining 28%. For the number of establishments and workers, the contribution of each block of variables is quite similar.

The total revenues of the hotel sector in La Palma Island from the international segment during September 2020-December 2020 and January 2021-August 2021 (one-year lags of the during and post-eruption periods) were €94,548.7 and €692,975.2, respectively. These figures are calculated as the sum of the products of monthly average daily rates times the number of foreign tourists in each period.[10] Based on the estimated percentage drops in demand, we estimate the volcano eruption has produced revenue losses for the hotel sector of around €72.518 and €447,315 during and post-eruption, respectively.

We have performed some robustness checks to our analysis. First, rather than considering the international segment only, we have re-estimated the model using the total number of tourists (including international, domestic and local tourists). The estimates are presented in Appendix, Table A9. We document that (i) the effect of the volcano on total demand in La Palma is smaller in magnitude as compared to Table 4 and (ii) the effect is relatively greater in the post-eruption period (-44.6% and -49.6%, respectively), being the difference in the coefficient estimates statistically significant (chi2(1)=17.23, p-value<0.001). The estimates for the number of hotel establishments and employees remain almost unchanged. Second, we have conducted the following placebo exercise. Restricting the sample to the pre-treatment period (September 2020-August 2021), we have generated a fake treatment starting in May 2021 (to have four 'treatment' periods). As expected, no significant difference in none of the three outcomes is detected (available upon request).

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[10] We acknowledge that the Average Daily Rate (ADR) is an imperfect measure of prices as it refers to the average daily revenues obtained by a representative hotel per occupied room. The ADR is drawn from the Hotel Occupancy Survey as a weighted average of the ADR per hotel category. See INE (2022) for further details on this.

6. DISCUSSION AND CONCLUSIONS

Climate change is accelerating the occurrence of natural disasters, imposing important negative economic effects on affected communities. This paper has evaluated the short-term impacts of La Palma volcano 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 have studied the impact of the eruption on international tourism demand, hotel supply and the number of hospitality workers during and after the eruption. Our empirical strategy has allowed for common unobserved shocks affecting the three outcomes using seemingly unrelated regression. Moreover, we have 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 (-76.7%) and after (-64.5%) the eruption. Hotel supply is found to have also declined as a response to the natural hazard. The effects appear to be slightly greater after the eruption period (34.8%) than during the event (38.2%). In a similar fashion, the number of hotel workers has declined by 30.6% and 27.7% during and after the volcano eruption, respectively. However, there is no evidence of spillover effects on the nearby islands of Tenerife and La Gomera, implying the volcano has only caused local effects.

Given the high dependence of island economies like La Palma to 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 inter-sectoral linkages (Figini & Patuelli, 2022).

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 policy making. 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 damages 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 to the economy, but they could be followed by long run economic gains (Guimaraes et al., 1993). As per Leiter et al. (2009), 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. Given that the negative short-term effects are mostly demand-driven, public authorities should also consider the need for developing promotional campaigns aimed at alleviating tourists' risk aversion.

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. 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 alike extreme events. In this regard, the quantification of the losses of natural disasters might be relevant for increasing the social and political awareness about the need for climate-change mitigation policies.

The paper has some limitations that we envisage as avenues for future research. First, we have taken touristic 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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APPENDIX

The effect of natural disasters on tourism demand, supply, and labour markets: Evidence from La Palma volcano eruption

Table A1. List of municipalities in each touristic zone (INE classification)

Touristic zone	Municipalities included	Touristic zone	Municipalities included
Gran Canaria	Agaete	**Lanzarote**	Arrecife
	Agüimes		Haría
	Aldea de San Nicolás, La		San Bartolomé
	Artenara		Teguise
	Arucas		Tías
	Firgas		Tinajo
	Gáldar		Yaiza
	Ingenio	**Tenerife**	Adeje
	Mogán		Arafo
	Moya		Arico
	Las Palmas de Gran Canaria		Arona
	San Bartolomé de Tirajana		Buenavista del Norte
	Santa Brígida		Candelaria
	Santa Lucía de Tirajana		Fasnia
	Santa María de Guía de Gran Canaria		Garachico
	Tejeda		Granadilla de Abona
	Telde		Guancha, La
	Teror		Guía de Isora
	Valleseco		Güímar
	Valsequillo de Gran Canaria		Icod de los Vinos
	Vega de San Mateo		Matanza de Acentejo, La
South of Gran Canaria	Mogán		Orotava, La
	San Bartolomé de Tirajana		Puerto de la Cruz
El Hierro	Frontera		Realejos, Los
	Pinar de El Hierro, El		Rosario, El
	Valverde		San Cristóbal de La Laguna
La Palma	Barlovento		San Juan de la Rambla
	Breña Alta		San Miguel de Abona
	Breña Baja		Santa Cruz de Tenerife
	Fuencaliente de la Palma		Santa Úrsula
	Garafía		Santiago del Teide
	Llanos de Aridane, Los		Sauzal, El
	Paso, El		Silos, Los
	Puntagorda		Tacoronte
	Puntallana		Tanque, El
	San Andrés y Sauces		Tegueste
	Santa Cruz de la Palma		Victoria de Acentejo, La
	Tazacorte		Vilaflor de Chasna
	Tijarafe	**South of Tenerife**	Adeje
	Villa de Mazo		Arico
La Gomera	Agulo		Arona
	Alajeró		Candelaria
	Hermigua		Fasnia
	San Sebastián de la Gomera		Granadilla de Abona
	Valle Gran Rey		Guía de isora
	Vallehermoso		Güímar
Fuerteventura	Antigua		San Miguel de Abona
	Betancuria		Santiago del Teide
	Oliva, La		Vilaflor de Chasna
	Pájara		
	Puerto del Rosario		
	Tuineje		

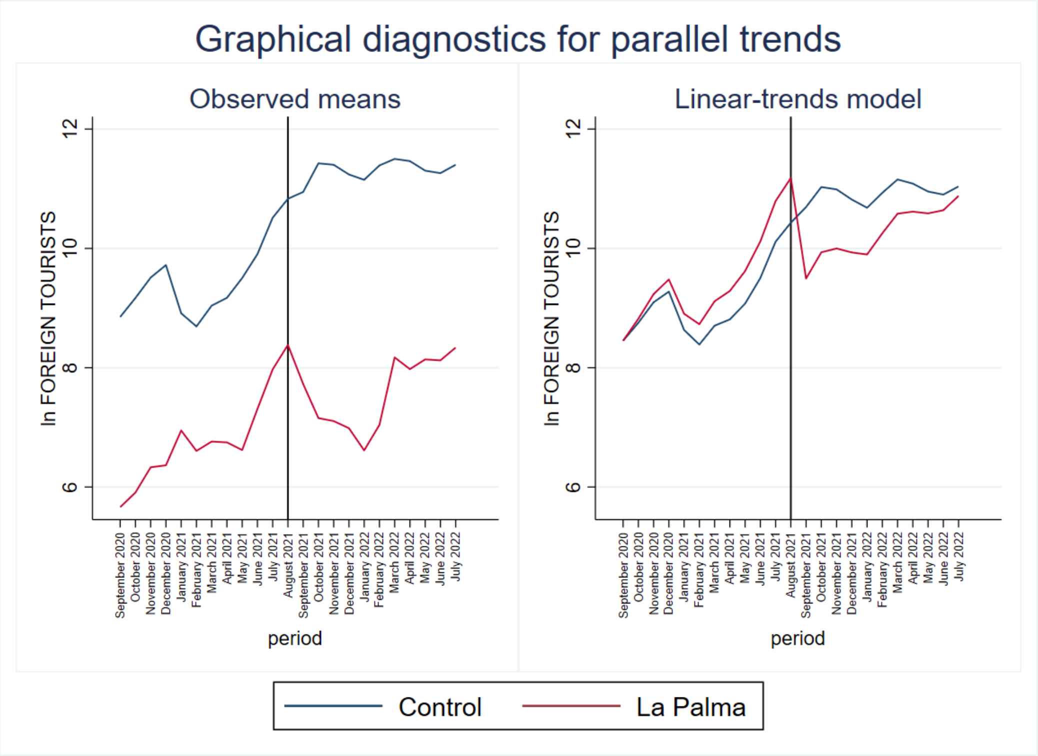

Figure A1. Visual inspection of parallel trends between La Palma and controls for ln FOREIGN TOURISTS in the pre-treatment period (observed means on the left; predicted linear-trends model on the right)

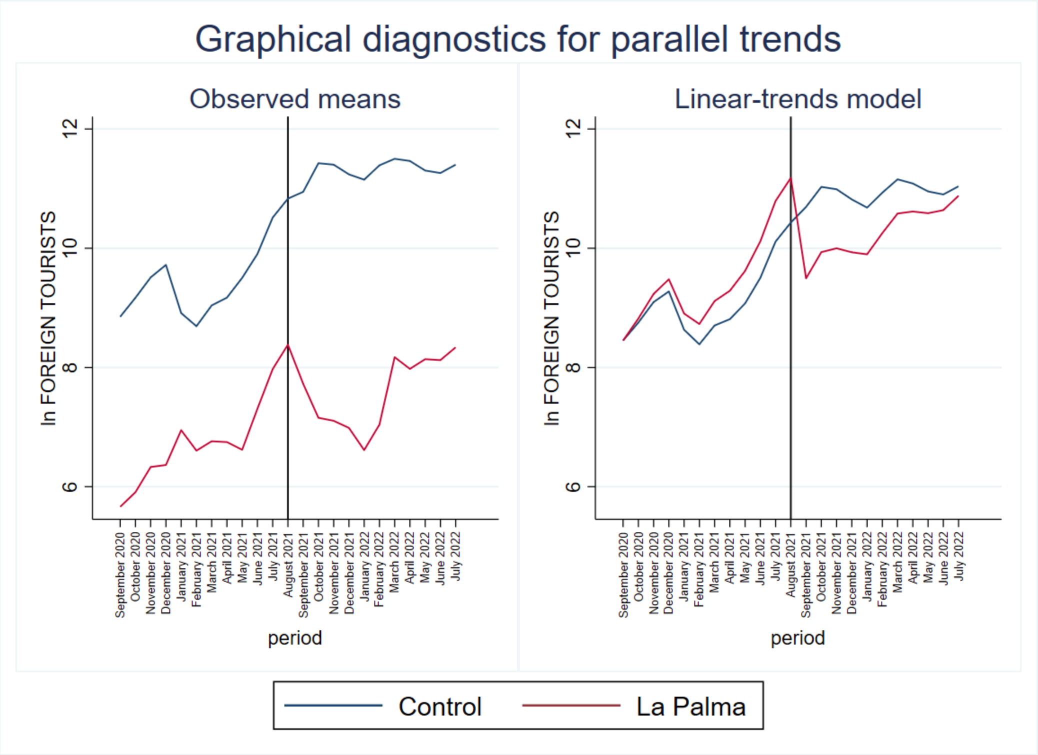

Figure A2. Visual inspection of parallel trends between La Palma and controls for ln HOTELS in the pre-treatment period (observed means on the left; predicted linear-trends model on the right)

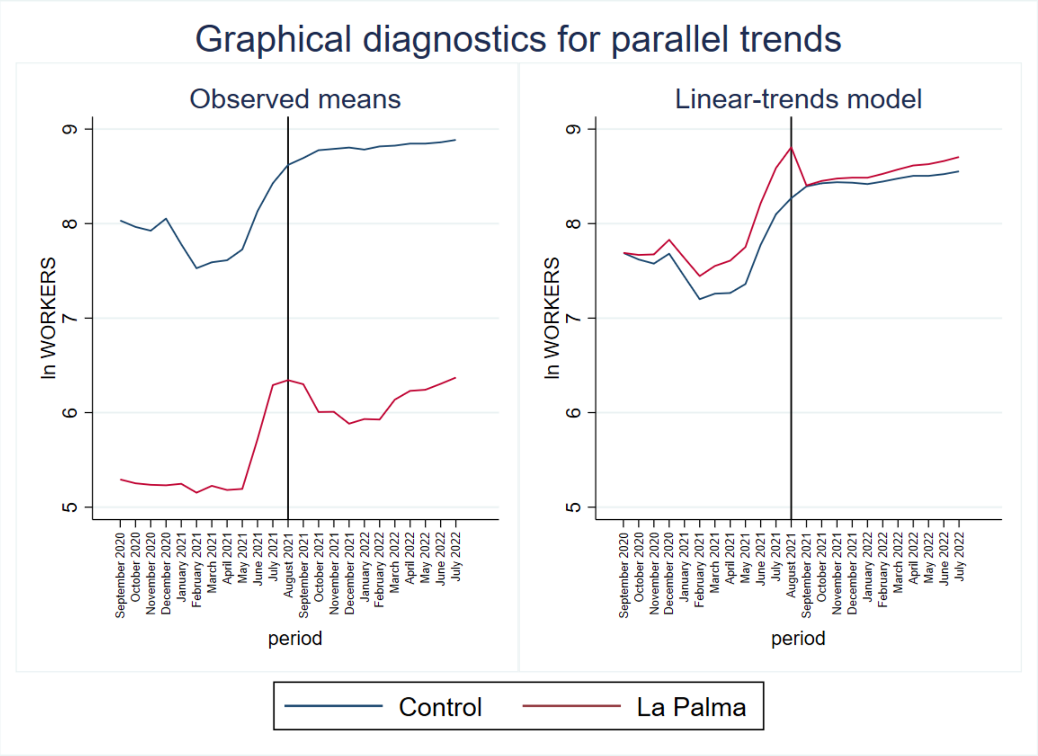

Figure A3. Visual inspection of parallel trends between La Palma and controls for ln WORKERS in the pre-treatment period (observed means on the left; predicted linear-trends model on the right)

Table A2. DiD estimands of interest

	Post Eruption	*During Eruption*	*Pre-Eruption*	**Δ (a-c)**	**Δ (b-c)**
	(a)	(b)	(c)		
LaPalma (d)	$\alpha + \mu_{PALMA} + \beta_2 + \overline{\tau_{t,post}}$	$\alpha + \mu_{PALMA} + \beta_1 + \overline{\tau_{t,dur}}$	$\alpha + \mu_{PALMA} + \overline{\tau_{t,pre}}$	$\beta_2 + \overline{\tau_{t,post}} - \overline{\tau_{t,pre}}$	$\beta_1 + \overline{\tau_{t,dur}} - \overline{\tau_{t,pre}}$
Pot.treated (e)	$\alpha + \mu_{i,pot.trea} + \delta_2 + \overline{\tau_{t,post}}$	$\alpha + \mu_{i,pot.trea} + \delta_1 + \overline{\tau_{t,dur}}$	$\alpha + \mu_{i,pot.trea} + \overline{\tau_{t,pre}}$	$\delta_2 + \overline{\tau_{t,post}} - \overline{\tau_{t,pre}}$	$\delta_1 + \overline{\tau_{t,dur}} - \overline{\tau_{t,pre}}$
Non-treated (f)	$\alpha + \mu_{i,non.trea} + \overline{\tau_{t,post}}$	$\alpha + \mu_{i,non.trea} + \overline{\tau_{t,dur}}$	$\alpha + \mu_{i,non.trea} + \overline{\tau_{t,pre}}$	$\overline{\tau_{t,post}} - \overline{\tau_{t,pre}}$	$\overline{\tau_{t,dur}} - \overline{\tau_{t,pre}}$
Δ (d-f)	$\mu_{PALMA} + \beta_2 - \mu_{i,non.trea}$	$\mu_{PALMA} + \beta_1 - \mu_{i,non.trea}$	$\mu_{PALMA} - \mu_{i,non.trea}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_1}$
Δ (e-f)	$\mu_{i,pot.trea} + \delta_2 - \mu_{i,non.trea}$	$\mu_{i,pot.trea} + \delta_1 - \mu_{i,non.trea}$	$\mu_{i,pot.trea} - \mu_{i,non.trea}$	$\boldsymbol{\delta_2}$	$\boldsymbol{\delta_1}$

Note: the table presents E(Y|period=p, group=g), where Y is any of the three dependent variables, *p* denotes the three main periods (pre-eruption, during eruption and post-eruption) and *g* refers to each of the three groups (La Palma, potentially treated and non-treated). The parameters $\overline{\tau_{t,pre}}$, $\overline{\tau_{t,dur}}$ and $\overline{\tau_{t,post}}$ denote the (weighted by sample size) mean of the time fixed effects in the pre (t=1,.., 12), during (t=13, …, 16) and post (t=17, …, 23) periods, respectively. The parameter μ_{PALMA} is the fixed effect for La Palma Island and $\mu_{i,pot.trea}$ and $\mu_{i,non.trea}$ refer to the (weighted by sample size) mean of the fixed effects for potentially treated and non-treated units.

If we add dummy indicators for *Pot.treated*, *LaPalma*, *During* and *Post* to the model in (1) we obtain the following equations:

$$\begin{aligned}\ln FOREIGN\ TOURISTS_{it} \\ &= \alpha^T + \lambda_1{}^T During_t + \lambda_2{}^T Post_t + \theta_1^T LaPalma_i + \theta_2^T Pot.treated_i + \beta_1{}^T LaPalma_i \times During_t + \beta_2{}^T LaPalma_i \times Post.Eruption_t \\ &+ \delta_1{}^T Pot.treated_i \times During_t + \delta_2{}^T Pot.treated_i \times Post.Eruption_t + \mu_i{}^T + \tau_t{}^T + \varepsilon_{it}{}^T\end{aligned}$$

$$\begin{aligned}\ln HOTELS_{it} = \alpha^H + \lambda_1{}^H During_t + \lambda_2{}^H Post_t + \theta_1^H LaPalma_i + \theta_2^H Pot.treated_i + \beta_1{}^H LaPalma_i \times During_t + \beta_2{}^H LaPalma_i \times Post.Eruption_t \\ + \delta_1{}^H Pot.treated_i \times During_t + \delta_2{}^H Pot.treated_i \times Post.Eruption_t + \mu_i{}^H + \tau_t{}^H + \varepsilon_{it}{}^H\end{aligned}$$

$$\begin{aligned}\ln WORKERS_{it} = \alpha^W + \lambda_1{}^W During_t + \lambda_2{}^W Post_t + \theta_1^W LaPalma_i + \theta_2^W Pot.treated_i + +\beta_1{}^W LaPalma_i \times During_t + \beta_2{}^W LaPalma_i \times Post.Eruption_t \\ + \delta_1{}^W Pot.treated_i \times During_t + \delta_2{}^W Pot.treated_i \times Post.Eruption_t + \mu_i{}^W + \tau_t{}^W + \varepsilon_{it}{}^W\end{aligned}$$

Table A3. DiD estimands of interest under alternative model specification

	Post Eruption (a)	*During Eruption* (b)	*Pre-Eruption* (c)	**Δ (a-c)**	**Δ (b-c)**
LaPalma (d)	$\beta_2 + \theta_1 + \lambda_2 + \alpha$	$\beta_1 + \theta_1 + \lambda_1 + \alpha$	$\theta_1 + \alpha$	$\beta_2 + \lambda_2$	$\beta_1 + \lambda_1$
Pot.Treated (e)	$\delta_2 + \theta_2 + \lambda_2 + \alpha$	$\delta_1 + \theta_2 + \lambda_1 + \alpha$	$\theta_2 + \alpha$	$\delta_2 + \lambda_2$	$\delta_1 + \lambda_1$
Controls (f)	$\lambda_2 + \alpha$	$\lambda_1 + \alpha$	α	λ_2	λ_1
Δ (d-f)	$\beta_2 + \theta_1$	$\beta_1 + \theta_1$	θ_1	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_1}$
Δ (e-f)	$\delta_2 + \theta_2$	$\delta_1 + \theta_2$	θ_2	$\boldsymbol{\delta_2}$	$\boldsymbol{\delta_1}$

Note: the table presents E(Y|period=p, group=g), where Y is any of the three dependent variables, *p* denotes the three possible time periods (pre-eruption, during eruption and post-eruption) and g refers to each of the three groups (La Palma, potentially treated and non-treated). Fixed effects are excluded since we have included the parameters for During, Post, LaPalma and Pot.Treated which result from a linear combination of fixed effects (temporal and geographic).

Table A4. Seemingly unrelated Difference-in-differences estimation results (SUR-DiD) expanded with La Palma, During, Post and Pot.treated dummies.

Variables	(1) Ln FOREIGN TOURISTS	(2) Ln HOTELS	(3) Ln WORKERS
La Palma	-2.862***	-1.093***	-2.482***
	(0.053)	(0.032)	(0.027)
During	2.710***	0.686***	0.882***
	(0.129)	(0.047)	(0.076)
La Palma × During	-1.457***	-0.426***	-0.365***
	(0.090)	(0.061)	(0.050)
Post	2.708***	0.735***	0.940***
	(0.156)	(0.052)	(0.041)
La Palma × Post	-1.037***	-0.481***	-0.325***
	(0.123)	(0.070)	(0.059)
Pot.Treated	0.861***	0.586***	-2.314***
	(0.108)	(0.102)	(0.124)
Pot. Treated × During	-0.306*	-0.235	-0.350
	(0.180)	(0.221)	(0.242)
Pot.Treated × Post	-0.328	-0.174	-0.358
	(0.252)	(0.209)	(0.268)
Constant	8.966***	3.590***	7.983***
	(0.111)	(0.024)	(0.043)
Unit fixed effects	YES	YES	YES
Period fixed effects	YES	YES	YES
Observations	184	184	184
R-squared	0.974	0.967	0.980

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

Coefficients for LaPalma and Pot. Treated show structural differences of the three outcomes with respect to Controls. Coefficients for During and Post show the trend of the three outcomes, with respect to pre-eruption levels.

Table A5. Decomposition of DiD estimates for Ln FOREIGN TOURISTS equation

	Post.Eruption (a)	*Eruption* (b)	*Pre.Eruption* (c)	**Δ (a-c)**	**Δ (b-c)**
LaPalma (d)	7.775 ***	7.384***	6.104***	1.671***	1.280***
Pot.Treated (e)	12.207***	12.258***	9.827***	2.380***	2.431***
Controls (f)	11.674***	11.703***	8.966***	2.708***	2.737***
Δ (d-f)	-3.899***	-4.319***	-2.862***	**-1.037*** **	**-1.457*** **
Δ (e-f)	0.533***	0.555***	0.861***	**-0.328**	**-0.306**

*** p<0.01, ** p<0.05, * p<0.1

Table A6. Decomposition of DiD estimates for Ln HOTELS equation

	Post.Eruption (a)	*Eruption* (b)	*Pre.Eruption* (c)	**Δ (a-c)**	**Δ (b-c)**
LaPalma (d)	2.752 ***	2.757***	2.498***	0.255***	0.259***
Pot.Treated (e)	4.738***	4.627***	4.176***	0.562***	0.451***
Controls (f)	4.326***	4.276***	3.590***	0.735***	0.686***
Δ (d-f)	-1.573***	-1.519***	-1.093***	**-0.481*** **	**-0.426*** **
Δ (e-f)	0.413***	0.351***	0.586***	**-0.174**	**-0.235**

*** p<0.01, ** p<0.05, * p<0.1

Table A7. Decomposition of DiD estimates for Ln WORKERS equation

	Post.Eruption (a)	*Eruption* (b)	*Pre.Eruption* (c)	**Δ (a-c)**	**Δ (b-c)**
LaPalma (d)	6.179 ***	6.018***	5.501***	0.679***	0.517***
Pot.Treated (e)	6.315***	6.200***	5.668***	0.646***	0.532***
Controls (f)	8.986***	8.864***	7.982***	1.004***	0.882***
Δ (d-f)	-2.807***	-2.846***	-2.482***	**-0.325*** **	**-0.365*** **
Δ (e-f)	-2.671***	-2.664***	-2.314***	**-0.358**	**-0.350**

*** p<0.01, ** p<0.05, * p<0.1

Table A8. 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	-0.591***	-0.426***	-0.365***
	(0.129)	(0.061)	(0.050)
La Palma × Post	-0.686***	-0.481***	-0.325***
	(0.147)	(0.070)	(0.059)
Pot.treated × During	-0.332	-0.235	-0.350
	(0.234)	(0.221)	(0.242)
Pot.treated × Post	-0.341	-0.174	-0.358
	(0.278)	(0.209)	(0.268)
Constant	10.284***	3.590***	7.983***
	(0.045)	(0.024)	(0.043)
Corr ($\varepsilon_{it}{}^{T}$, $\varepsilon_{it}{}^{H}$)		0.765	
Corr ($\varepsilon_{it}{}^{T}$, $\varepsilon_{it}{}^{W}$)		0.836	
Corr ($\varepsilon_{it}{}^{H}$, $\varepsilon_{it}{}^{W}$)		0.874	
Unit fixed effects	YES	YES	YES
Period fixed effects	YES	YES	YES
Observations	184	184	184
R-squared	0.976	0.967	0.980

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

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