Extreme Weather Events and PDO wine exports

Daniele Curzi[a], Federico Zilia[a,b], Cristina Vaquero Piñeiro[c], and Alessandro Olper[a]

[a] *Department of Environmental Science and Policy, University of Milan, Italy*

[b] *University School for Advanced Studies, Pavia, Italy*

[c] *Department of Economics, Roma Tre University, Italy*

Abstract

This paper exploits regulatory differences in the EU Geographical Indications policy between Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) to analyze whether stricter compliance rules make the former group more exposed to the negative consequences of extreme weather events. For this purpose, we empirically analyze the effect of heat and cold waves on Italian wine exports, distinguishing the effect across PDO and PGI wines. Weather conditions significantly affect wine yield, quality, production processes, and longevity, affecting prices and revenues. We rely on a rich database covering about 7,000 Italian municipalities, providing information on wine exports over the 2004-2018 period, which we integrate with geospatial meteorological data. Using an event study approach, the results indicate that heat waves negatively affect PDO wine exports. In contrast, PGI wine exports are not significantly affected by heat waves. The findings contribute to the agricultural economics literature, offering empirical evidence on the impact of climatic conditions on agri-food exports. Additionally, the study addresses the political debate within the EU concerning the adaptation capacity of GI producers to extreme weather events compared to non-PDO producers, emphasizing the challenges faced by the former due to strict regulations limiting adaptive strategies.

Keywords: PDO Wine; Extreme Weather Events; Wine Exports; Geographical Indications; Adaptation.

1 Introduction

The effects of climate change on agricultural productivity have been extensively studied in the literature. As it is well-known, agriculture will be one of the sectors that will be mostly affected by changes in climatic conditions. Fewer contributions have considered the direct effect of extreme weather events on agricultural trade (e.g., Jones and Olken, 2010). Evidence from the literature suggests that, on the one hand, being associated with a likely drop in agricultural yield (see for example Schlenker and Roberts, 2009 and Hultgren et al., 2022), extreme weather events negatively affect agricultural exports. On the other hand, trade may be considered one of the most valuable adaptation instruments (Gouel and Laborde, 2021; Janssens et al., 2020), as countries/regions adversely affected by climate change, especially in the agricultural sector, can mitigate these effects by relying more extensively on imported products. Related to this last point, a recent contribution by Garcia-Verdu et al. (2022) highlights that the effect of weather shocks on agricultural productivity is significantly more pronounced in those countries relying to less extent on imported intermediate inputs.

Against this background, this paper aims to understand the effect of extreme weather events, particularly heat and cold waves, on Italian wine exports by considering the case of Italian Geographical Indications (GIs) wines, and in particular, the case of Protected Designation of Origin (PDO). GIs are collectively held property rights that provide legal support to the producers of certain agri-food products against their imitation or name misuse (Kerr and Clark, 2022; Pagliacci and Salpina, 2022). These products must follow strict regulations in terms of the production process and use of inputs to be certified in order to receive such legal protection. Weather conditions affect wines' yield, quality, production process, and longevity, which strongly influence wines' prices and revenues (Ashenfelter and Storchmann, 2016). The increase in global temperatures, a consequence of climate change, is highlighted as a major factor impacting wine production. While higher temperatures have historically contributed to advancements in wine grape harvests and improved quality ratings, excessive heat may harm wine quality, particularly for high-quality wines in regions at the margins of their climatic limits.

Changes in climatic conditions require wine producers to adapt to it anyway. However, in contrast with other annual crops, any adjustment in the wine sector will be likely to take more time as wine is a perennial crop. Moreover, adaptation is limited in Europe and mostly in major wine producers such as Italy and France due to the link between wines and geography. In addition to issues such as wine planting rights, the GI certification does not allow wine producers to rely on many of the widely diffused potential adaptation strategies, such as drought-resistant varieties. Regulations are particularly severe for PDO wine producers, as they cannot rely on inputs originating from outside the designated area or on the use of different grape varieties than those reported in the regulation. Therefore, unless the EU regulation is somehow relaxed, PDO wine production may be among those that will suffer the most severe consequences of climate change (Ashenfelter and Storchmann, 2016; Clark and Kerr, 2017).

We conduct an event study analysis to assess the effect of extreme events on wine exports. This approach allows us to consider the dynamic effect of the weather shock and test the pre-trend assumption. Our empirical analysis relies on a unique database providing information on exports of about 7,000 Italian municipalities distinguishing the export values and volumes of GI and non-GI wines for the period 2004-2018. Trade data are matched with geospatial climate and socio-demographic data. Using these data, our purpose is to estimate whether PDO wine exports are affected by extreme weather events vs. non-PDO wine exports.

The market of GIs has an economic relevance that goes beyond the promotion of the economic growth of rural development communities. In the case of Italy, every year, GIs represent around 20% of the total Italian agri-food revenue. The main features of GIs are strictly related to local agronomic conditions and production practices, a concept summarized by the term terroir (Josling (2006)). Among different local determinants of GI characteristics, climate is certainly one of the most important ones. This is especially true for terroir-based GIs, which do not need any particular locally tied human capital, and their characteristics are deeply rooted in the local agronomic conditions, such as in the case of wine and olive oils (Clark and Kerr, 2017). Within the GIs framework, climate is assumed to be static, in a way that it contributes to providing standard product characteristics. However, in the climate change context, adverse or fluctuating climate may lead to changes in such conditions in a way that some of the yearly production may not be considered suitable for the GI certification. From this perspective, the effect of adverse weather conditions may be more severe for PDO products than for any other agri-food product, as they can use only domestic (local) inputs. Therefore, PDO producers cannot rely on the use of intermediate inputs coming from outside the local production area, or they cannot rely on any other adaptation strategy that may lead the final product to depart from the characteristics envisaged by the GI regulation. Therefore, the mitigation of potential losses due to such climatic events is rather limited for PDO producers.

The main results suggest that extreme weather events severely hit PDO wine exports, particularly heat waves. When considering heat waves, our results suggest that heat waves are particularly harmful to Italian municipalities acknowledged with only PDO. In contrast, our results suggest that cold waves do not affect differently PDO producers and non-PDO producers.

The main contribution of the paper is two-fold. First, we contribute to the seldom investigated relationship between extreme weather events and agri-food exports using a unique database and focusing on wine, which represents the Italian flagship agri-food product, whose export value covers almost one-fourth of the whole Italian exports in the food sectors. Second, our analysis provides the first empirical contribution to the contentious debate concerning the adaptation capacity of PDO producers to extreme weather events compared to non-PDO producers, emphasizing the challenges faced by the former due to strict regulations limiting adaptive strategies.

2 Effect of change in climatic conditions on wine production

The effects of climate change, and especially the rise in temperature, are likely to have ambiguous effects on wine production and quality. Climate is a core determinant of wine production. Among other things, weather conditions affect wines' yield, quality, production process, and longevity, which in turn have a strong influence on wines' prices and revenues (Ashenfelter and Storchmann, 2016). Climate change can take different forms, and thus, it may impact wine production in different ways. However, the increase in temperature over the last decades probably had the highest impact on wine production. Among various consequences, one of the most relevant ones is the advancement of wine grape harvest during the recent decades (Cook and Wolkovich, 2016). Interestingly, this has been also accompanied by a simultaneous increase in wine quality ratings. This is because wine quality is often associated with early harvesting dates, especially in traditional wine producers such as Italy and France. Such a relationship, however, has been proven to disappear when considering the more recent years, as, after a certain tipping point, high temperatures may be detrimental to wine quality (Cook and Wolkovich, 2016; Van Leeuwen and Darriet, 2016).

In general, the consequences of an increase in temperature on wine quality may be either positive or negative and highly heterogeneous across different regions. As a general rule, producers of high-quality wines located in regions at the margins of their climatic limits, are likely to experience a reduction in wine quality. Conversely, those producers located in regions where the increase in temperature may allow them to reach the optimal climatic regimes are likely to see their wine quality increase (Jones et al., 2005). Therefore, the production of wines in the Mediterranean area is likely to suffer more from the effect of an increase in temperature rather than North-Europe countries, such as, for instance, the UK. Using the words of Mozell and Thach (2014), p. 85: "Vast portions of Europe on the Mediterranean coastline, especially Italy, Greece, and France, may become completely inhospitable to grape production by 2050. . . .Southern England, by contrast, is resembling Champagne and has had several vintages of note."

3 Data

In our empirical analysis, we rely on different data sources. First, starting from the entire sample of Italian municipalities, we map those that are included within PDO and PGI regions of origin. The presence of GIs has been reconstructed at the year-space level in order to account for their time-space variability. In this way, we are able to take into account not only which municipalities are allowed to produce them but also since when. Such disaggregated spatial level of data is crucial for our analysis (Crescenzi et al., 2022) since the demarcated areas of GIs do not coincide with administrative regional or national areas. As a second step, we add trade data from a detailed firm-level 8-digit (Combine Nomenclature 8) database provided by the Italian National Institute of Statistics (ISTAT). Data refers to export flows at the municipality level and distinguishes between GI and non-GI wines. Export flows are, however, registered by referring to the fiscal code of the head office of exporting firms.

We integrate export data with the Agrometeorological indicators (AgERA5) provided by the European Commission Copernicus database. AgERA5 aggregates data to daily time steps at the local time zone and corrected towards a fine topography at a 0.1 °C spatial resolution, translating to approximately 11 km at the equator for both latitude and longitude (Boogaard et al., 2020). The correction to the 0.1° grid was realized by applying grid and variable-specific regression equations to the ERA5 dataset interpolated at 0.1° grid. We extracted the daily mean of '2m temperature' as air temperature at a height of 2 meters above the surface. Moreover, we collected daily maximum temperature and precipitation flux as the total volume of liquid water (mm3) precipitated over the period 00h-24h local time per unit of area (mm2) per day. Then, these data are downscaled using the ISTAT shapefile to align with municipalities' boundaries. After that, we aggregated the daily data to obtain annual mean temperatures and total annual precipitation for each Italian municipality. We focus on 'extreme' events like heat waves (HWs) measured as periods of at least three consecutive days where the daily maximum temperature is above its 99th percentile from the climatological baseline of 1994-2014 (Rousi et al., 2023). Cold waves (CWs), conversely, are defined as periods of at least three consecutive days with maximum temperature below its 2nd percentile. These climatic variables are useful because heat and cold waves significantly impact wine production by affecting the grapes' growth, ripening, and overall health. Extreme heat can accelerate ripening, potentially leading to unbalanced wines with higher alcohol and lower acidity, whereas cold waves can damage vines, delay ripening, and reduce yields. Both conditions challenge vineyard management, requiring adjustments to preserve grape quality and ensure the production of high-quality wines (Santos et al., 2020).

3.1 The distribution of Italian wines

The revision of the Common Agricultural Policy (CAP) in 2008 led to the reform and the entry into force of the new Common Market Organization for Wine, established by the publication of Regulation EC 479/2008 and the subsequent Regulation EC 441/09 (Alston and Gaeta, 2021). These regulations introduced significant changes regarding the classification of wines and their labeling practices. The main objectives of the reform were to increase the competitiveness of wine producers, consolidate the reputation of European wines, regain market share in non-European demand, protect the traditions of European viticulture, and strengthen the social and environmental practices in rural areas. Regulation EC 479/20081 established that starting from the 2009/2010 wine campaign, community wines were to be classified into the following types: GIs and non-GIs. The former highlights a specific link to the geographical territory (also known as terroir) and is distinguished into PDO and PGI. Specifically, PDO wines require the use of grapes exclusively from a specific geographical area (Marchini et al., 2014), while PGI wines may also use grapes from other areas, maintaining at least 85% of grapes from that specific region. On the other hand, the non-GIs do not show a specific relation to the terroir and correspond, before the reform, to table wines (in Italian, 'vino da Tavola', VDT). Therefore, these wines are not subject to a particular production specification. In Italy, the PDO category includes Controlled and Guaranteed Designation of Origin (DOCG) wines and Controlled Designation of Origin (DOC) wines. DOCG wines, while similar to DOC wines, have more stringent regulations, better qualitative characteristics, and renewed qualitative analysis at bottling (Alston and Gaeta, 2021). The Italian wines belonging to the PGI category are Typical Geographical Indication (IGT) wines, such as Vin de pays (Aosta Valley) and Landwein (Alto Adige). Figure 1 shows the diffusion of geographical indications of Italian wines at the municipal level in Italy in 2018. Among the areas with the most PDO and/or PGI wines are the municipalities between Veneto and Friuli with Conegliano Valdobbiadene Prosecco DOCG, parts of Piedmont, Tuscany, Lazio, Campania, Sicily, and some municipalities in Sardinia with wines like Alghero DOC or Arborea DOC. The areas less suited to produce GIs or non-GIs wines are those of the Alpine arc due to pedoclimatic reasons. Currently, in Italy, there are 341 DOC wines, 78 DOCG wines (419 PDOs in total), and 118 IGT wines, i.e., PGIs.

3.2 Italian Heat and Cold Waves

Heat waves and cold waves are detrimental to public health, the environment, and the vegetative process of grapevines (Gasparrini et al., 2015; Morlot et al., 2023). With rising temperatures and the effects of climate change, the intensity and duration of heat waves are expected to increase, while cold spells are likely to become less frequent (Smid et al., 2019). There are several methods in the literature to estimate heat and cold waves (Jacob et al., 2014; Serrano-Notivoli et al., 2022). In our study, using climatic data from Copernicus, we decided to adopt the methodology provided by Climatological EURO-CORDEX. A HW is defined as a period of at least three consecutive days during which the daily maximum temperature exceeds the 99th percentile of the daily maximum temperatures for the months of May to September for a specific reference period, in our case, from 1994 to 2014 (Christensen et al., 2014). Similarly, a CW is calculated as a period of at least three consecutive days where the daily maximum temperature is below the 2nd percentile during the meteorological winter months of December, January, and February for the reference period from 1994 to 2014. Given the climatic trend of our reference period, with temperatures generally increasing, we decided to implement this approach to capture only extreme events. In Figure 2, the aggregated heat waves from 2004 to 2018 for each Italian municipality are represented, divided into 4 different intensity colors depending on the number of HWs, plus ‘white’ where there are municipalities that have not experienced waves. The municipalities most affected are those along the Tyrrhenian coast, particularly in Tuscany, Lazio, and Campania, as well as significant events in Northern Italy. All these areas are highly suited to viticulture. The map in Figure 3 highlights the cold waves in Italian municipalities from 2004 to 2018. From the data collected, the areas most affected seem to be those of Central Italy, with some exceptions for certain municipalities in the northern North and the Alpine arc. However, it should be considered that the map shows the sum of all cold spells within a time frame from 2004 to 2018, and the maximum value of CWs reached was 10 in only 8 municipalities over 15 years.

4 Methodology

The empirical analysis relies on a difference-in-difference (DiD) approach. Our objective is to estimate the causal effect of heat and cold waves on PDO vs. non-PDO wine exports. We conduct an event study analysis through the estimation of a linear panel model. This approach allows us to estimate the dynamic effects of extreme events on PDO wine exports, and to control for the pre-trend assumption. We set our event study in a staggered DiD framework, to exploit both the cross-sectional and time variations of extreme weather events. To this purpose, we run the following two-way fixed effects linear panel model following Freyaldenhoven et al. (ming):

$$y_{it} = \sum_{m=-G}^{M} \beta_m z_{i,t-m} + \alpha_i + \gamma_t + \omega_{jt} + \epsilon_{it} \tag{1}$$

Where y_{it} is the (log of) wine export value. Our treatment variable is z_{it}, which captures heat and cold waves in municipalities acknowledged with PDO wine only. Specifically, our treatment variable is the interaction between a dummy variable taking the value of 1 for municipalities acknowledged with only PDO, and zero otherwise, with a dummy variable assuming the value of one if a municipality i experienced at least one heat (or cold) wave over the year t, and zero otherwise. The coefficient $\beta_{m=-G}^{M}$ allows the estimation of the dynamic treatment effect, where the outcome variable at time t can be affected by the treatment no more than M$\geq$0 years before the treatment at time t, and no more than G$\geq$0 years after the treatment. Our linear panel model also controls for unit fixed effects (α_i), time fixed effects (γ_t, and region-year fixed effects (ω_{jt}). Finally, ϵ_{it} captures shocks unobserved by our treatment.

It is worth noting that we refer as a treated group to those Italian municipalities that are acknowledged to produce only PDO and not PGI wines. Therefore, we do not consider as treated those Italian municipalities that are acknowledged with both PDO and PGI wines. This choice is motivated by the fact that the inclusion of the latter group of municipalities would not allow us to properly test our main research question (i.e., whether the limited adaptive possibilities to extreme events due to strict regulations cause a larger drop in PDO than in non-PDO wine exports), as trade data do not allow distinguishing export of PDO and PGI wines within the same municipality. Moreover, we impose some restrictions on the control group. First, we drop Italian municipalities that have never exported wine over the considered period. Second, we drop Italian municipalities acknowledged to produce both PDO and PGI, and Italian municipalities acknowledged to produce only PGI wine. Therefore, we restrict our estimation sample to Italian municipalities acknowledged with only PDO wine, and the control group is formed by those municipalities exporting PDO wine only that have been not affected by heat or cold waves over the considered period.

Moreover, for a comparative purpose, we run the same estimation as in 1, but considering the Italian municipalities acknowledged with PGI wine only. In this case, the control group is formed by municipalities exporting PGI wines only that are not affected by heat (cold) waves. This exercise allows us to better understand whether less strict regulation can attenuate the effect of extreme weather events.

Table I reports the summary statistics of the variables used in the estimation of the linear panel model, distinguishing the samples considered in the analysis. The sample of Italian municipalities acknowledged with PDO wine only is made by 13,694 observations (corresponding to about 1,200 municipalities), while the sample of Italian municipalities acknowledged with PGI wine only is made by 28,808 observations (corresponding to about 2,200 municipalities). Figures in the table show that, on average, the value and the quantity of wine exports are higher in the PDO sample. The dummy variables capturing heat and cold waves indicate that, on average, municipalities acknowledged with PGI wine are only slightly more hit by extreme events than the PDO sample. Finally, the population size in the two samples is very similar.

5 Results

The main results are reported in Figure 4. [1] Panel A reports the results of estimating the effect of heat waves on PDO wine exports in municipalities acknowledged with PDO only. [2] The p-value reported at the bottom of the figure allows rejecting the hypothesis

[1]Note that when running the same set of estimations of Figure 4 considering the (log of) export quantity, the results are in line with those obtained using the (log of) export value.

[2]Graphs are obtained using the STATA command *xtevent* from Freyaldenhoven et al. (ming).

of the existence of a pre-trend in the outcome variable during the pre-treatment period. The outcome variable is normalized at zero the year before the treatment (i.e., time -1 on the x-axis). The coefficients in the graph report the cumulative effect of heat waves on PDO wine exports over a 7-year period after the extreme event, in this case, the occurrence of at least one heat wave in a municipality i in year t. The results suggest that heat waves have a considerable negative and significant effect on PDO wine exports. The estimated negative coefficients, as suggested by the 95% confidence interval in the graph, are statistically significant starting from the third year after the heat wave. The magnitude of the coefficients is increasing until the sixth year after the occurrence of the heat wave. The magnitude of the dynamic cumulative effect is quite relevant: the occurrence of a heat wave leads to a reduction of PDO wine exports of about 200% over a six-year period with respect to the control group. Although the magnitude of the estimated effect is quite alarming, it is worth noting that our data indicate that, on average, the yearly share of PDO wine export value affected by heat waves over the considered period is 4%. This suggests that despite extreme events soaring, the negative consequences are experienced by a limited number of producers. In other words, notwithstanding the significant reduction in the affected producers, the Italian PDO wine exports as a whole have not been compromised in the considered period by heat waves.

Panel B of Figure 4 reports the results of the effect of heat weaves on PGI wine exports, when considering municipalities acknowledged with PGI wine only. The estimated coefficients show a negative dynamic effect of heat waves on PGI wine exports. The magnitude of the effect is considerably lower than that estimated for PDO wines, reaching a reduction of about 50% after six years. Notably, the estimated coefficients are not statistically significant at a conventional level. Therefore, we can conclude that heat waves do not have a significant negative effect on PGI wine exports.

From the results in Panel A and B of Figure 4, we can conclude that heat waves are significantly detrimental to PDO wine exports only. The different results obtained when considering the PGI wines sample support the hypothesis that extreme events more severely hit PDO wines due to their strict regulations, which do not allow them to take corrective actions when dealing with such climatic events.

In Panel C, we show the results of estimating the effect of cold waves on PDO wine exports. Although the estimated coefficients suggest a negative effect on wine exports, as shown by the confidence interval, these are never statistically significant at a conventional level. Similarly, in Panel D, when estimating the effect of cold waves on

PGI wine exports, the estimated coefficients do not suggest any significant effect.

As mentioned in the data section, a potential flaw of our trade data is that they refer to exporting firms having the head office in a given municipality. Therefore, we cannot a priori exclude that wine firms' production site is located in the same municipality where the head office is registered. This issue may be particularly relevant in bigger municipalities, where typically larger firms dislocate their headquarters. Therefore, as a robustness check, we run the same set of estimations presented in Figure 4, but excluding those municipalities with a population size larger than the 90th percentile of the sample distribution. We keep in our sample municipalities with a population size lower than 16,068 inhabitants. The results of this test are presented in Figure 4. The main results are in line with those presented in Figure 4, thus suggesting that heat waves have a significant negative effect on the export of PDO wine only, while the effect of cold waves is not significant either for PDO or for PGI wines.

6 Conclusion

This paper empirically estimates the effect of extreme weather events on wine exports. Our interest is particularly in detecting the potential heterogeneous impact between PDO and non-PDO wines. This is because, while non-PDO wines can freely adapt to emergency situations generated by extreme weather events, PDO wines have to respect stricter regulations, which limit their adaptive capacity to extreme events (e.g., using heat-resistant grape varieties). In line with the expectations, our results show that PDO wines are more severely hit by extreme weather events than non-PDO wines, especially by heat waves.

Our results provide, first, an empirical contribution to the literature dealing with the effect of climatic conditions on agri-food exports. Despite growing interest in this topic, little empirical evidence exists in the agricultural economics literature. Second, our analysis provides an important contribution to the overall assessment of the adaptation capacity of PDO producers to extreme weather events vs. non-PDO producers. This represents a quite debated political issue in the EU, as proved by the number of amendments required by the GI producers due to changes in climatic conditions.

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Table I: Summary Statistics

Municipalities acknowledged with PDO only					
Variable	Obs	Mean	Std. dev.	Min	Max
Export Value	13964	375668.5	3989507	0	1.46E+08
Export Quantity	13964	120393.8	1564365	0	5.94E+07
Dummy Heat Waves	13964	0.109	0.312361	0	1
Dummy Cold Waves	13964	0.271	0.4447042	0	1
Population	13964	6793.121	39542.48	51	882523

Municipalities acknowledged with PGI only					
Variable	Obs	Mean	Std. dev.	Min	Max
Export Value	28808	92708.9	1306536	0	5.59E+07
Export Quantity	28808	35520.5	639563.5	0	3.73E+07
Dummy Heat Waves	28808	0.139	0.3460137	0	1
Dummy Cold Waves	28808	0.352	0.4777588	0	1
Population	28808	7078.3	26446.2	76	966144

Notes: Authors' computation on data described in the main text

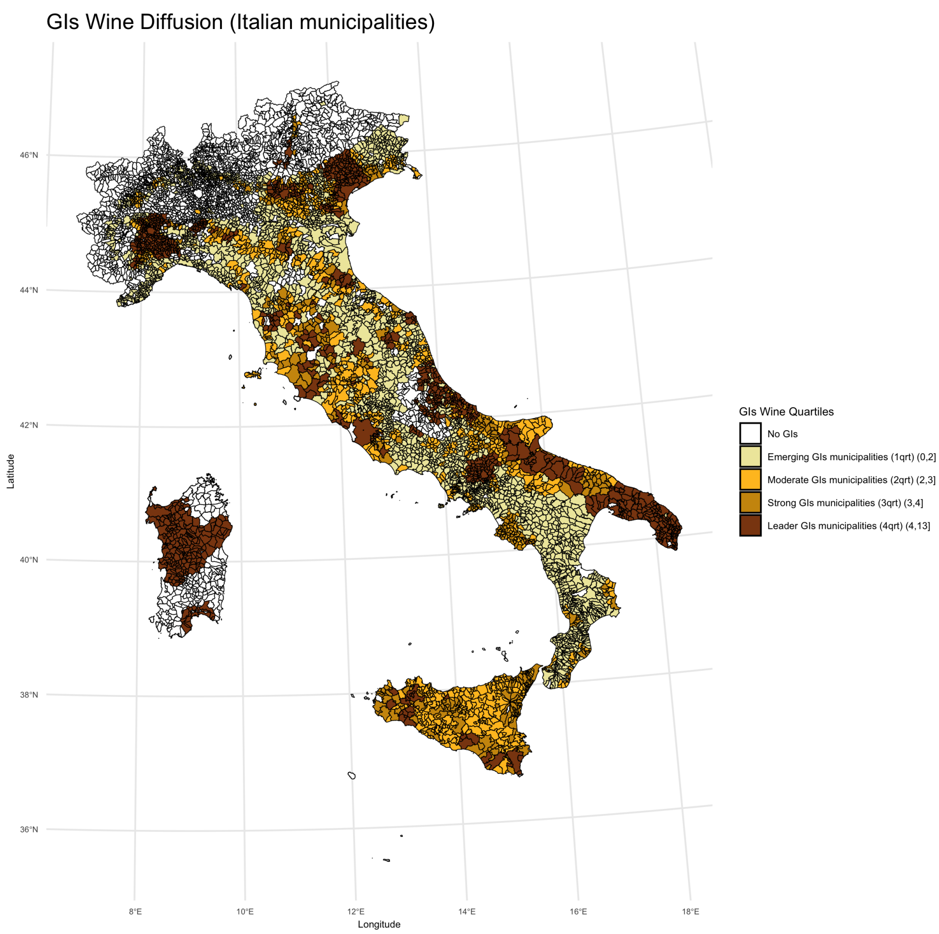

Figure 1: Distribution of GI wines in the Italian municipalities

Notes: See the data section for detailed information on the data matching

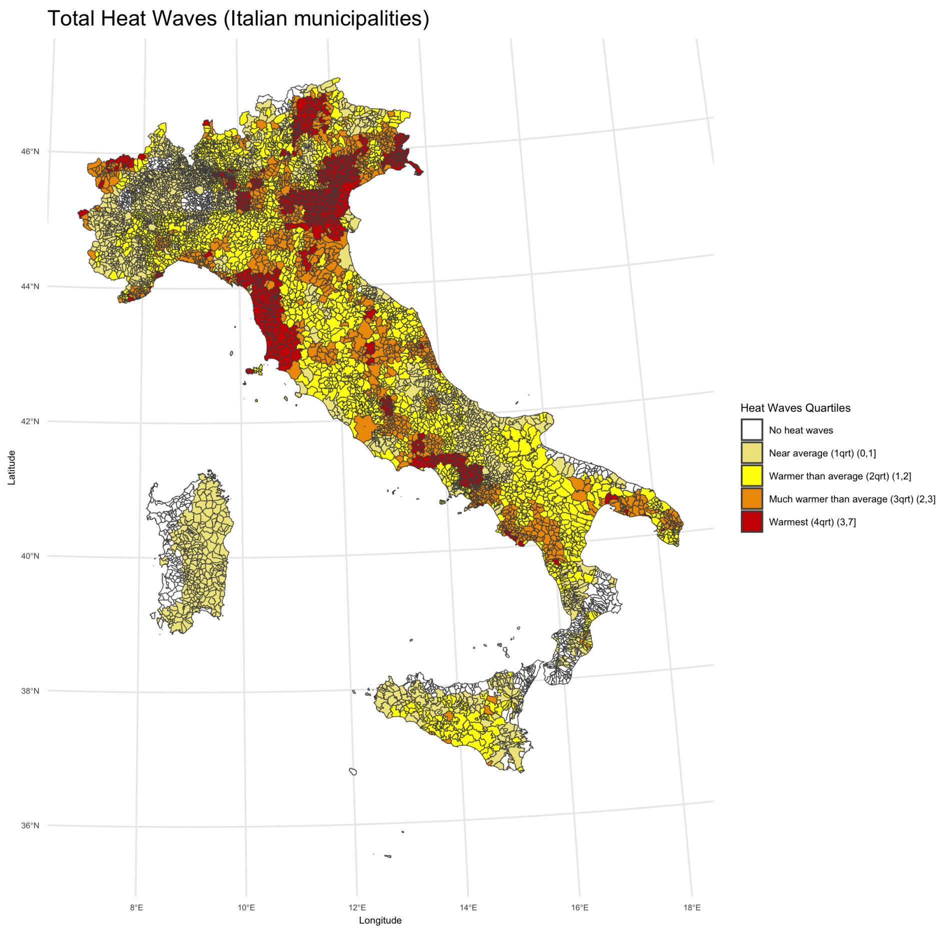

Figure 2: Total number of heat waves across Italian Municipalities (2004-2018)

Notes: See the data section for a detailed description for the data source and the methodology used to estimate heat waves

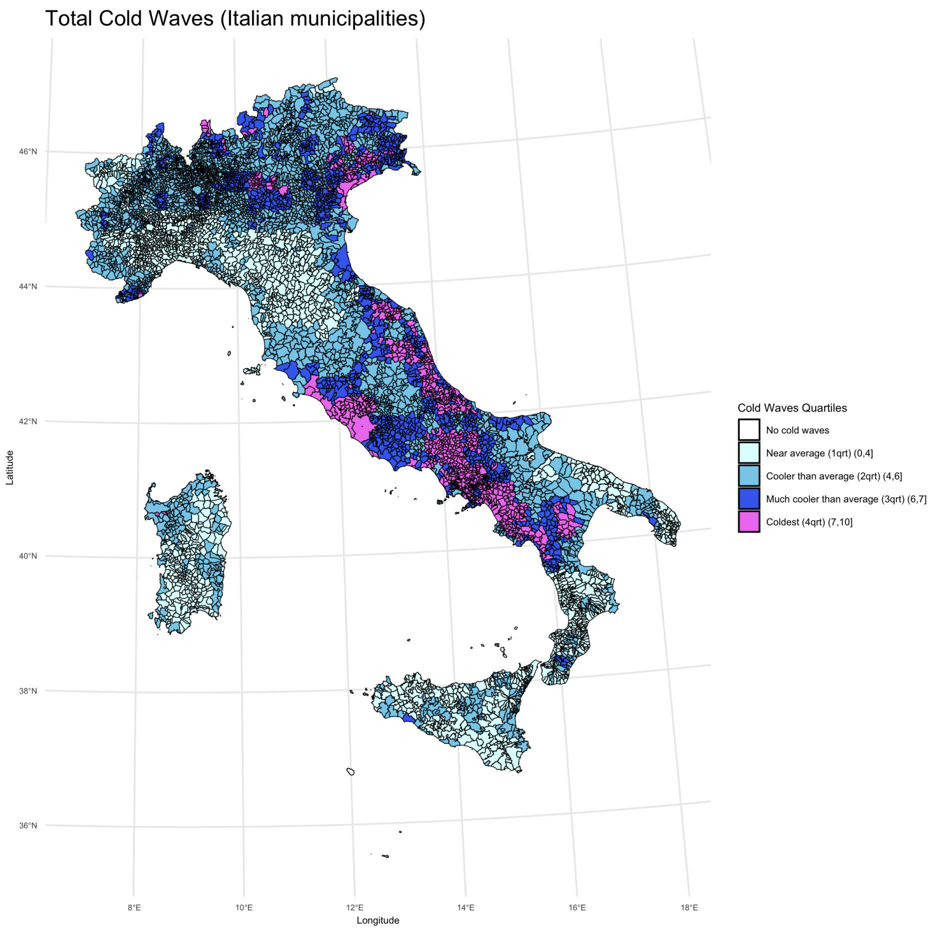

Figure 3: Total number of cold waves across Italian Municipalities (2004-2018)

Notes: See the data section for a detailed description for the data source and the methodology used to estimate heat waves

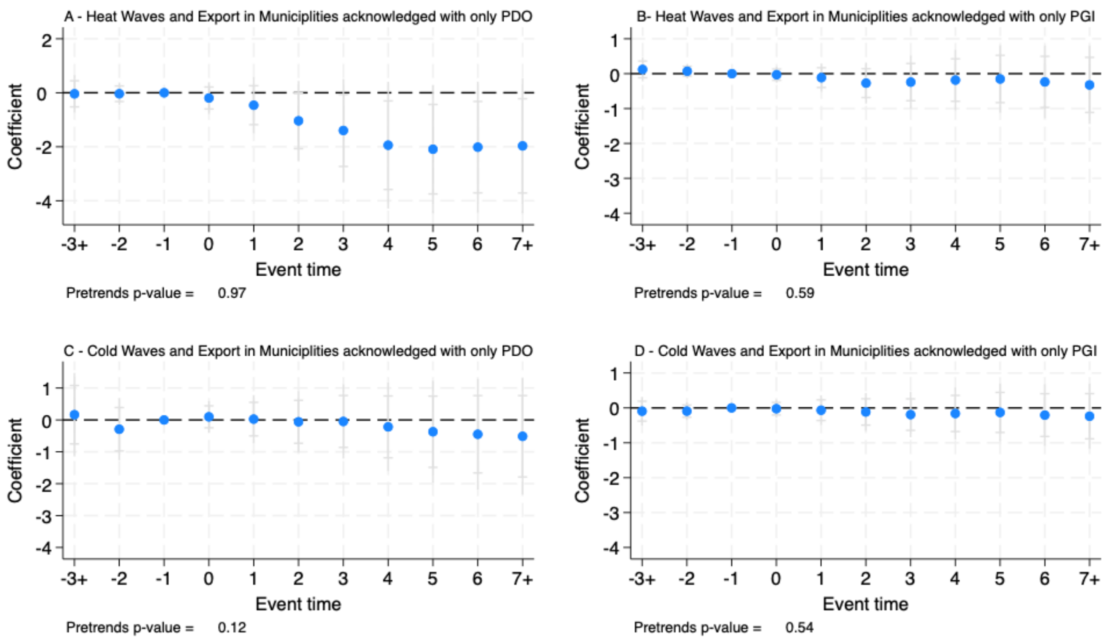

Figure 4: Effect of heat and cold waves on wine exports

Notes: Each figure reports the estimated coefficients of the event study analysis along with pointwise confidence intervals at 95% level. The sample of treated municipalities refers to municipalities acknowledged with either PDO or PGI wine only. Estimates are obtained using the xtevent Stata command by Freyaldenhoven et al. (2023)

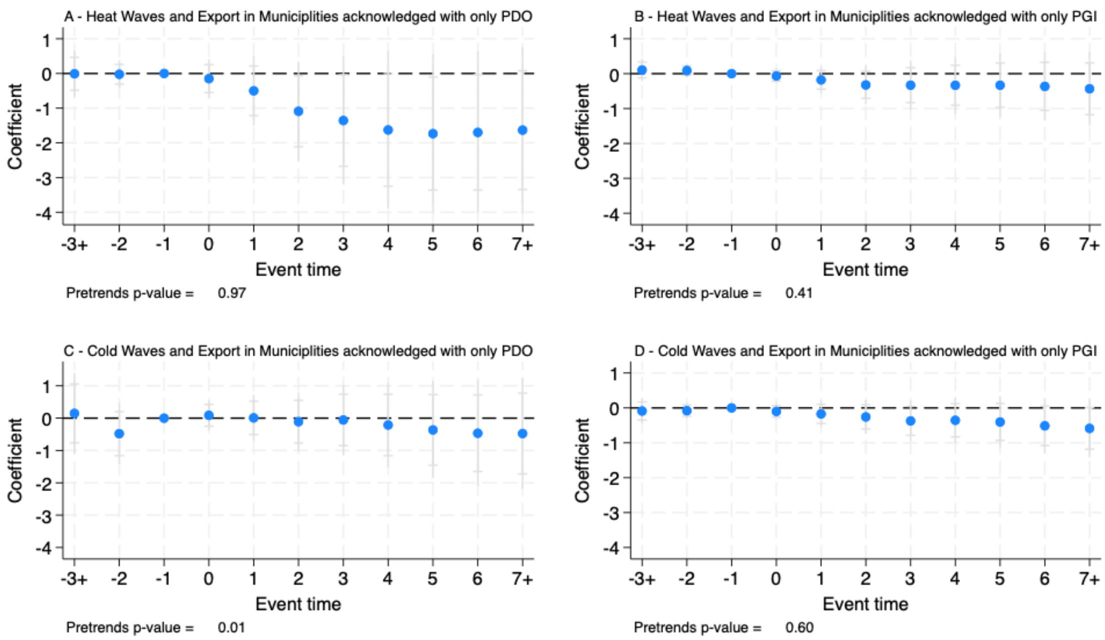

Figure 5: Effect of heat and cold waves on wine exports excluding larger municipalities

Notes: Each figure reports the estimated coefficients of the event study analysis along with pointwise confidence intervals at 95% level. The sample of treated municipalities refers to municipalities acknowledged with either PDO or PGI wine only. Estimates are obtained using the xtevent Stata command by Freyaldenhoven et al. (2023)