Bio-based and Applied Economics 7(2): 97-116, 2018
DOI: 10.13128/bae-7670

Full Research Article

Climate change and variations in mountain pasture values in the central-eastern Italian Alps in the eighteenth and nineteenth centuries

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Date of submission: 2017, 26th, January; accepted 2018, 18th, June

Abstract. This study investigates variations in pasture lease rents during the eighteenth and nineteenth centuries in a sector of the Italian Alps and how these correlate with climate changes. Analysis of the rents in the three data sets clearly demonstrates a sharp increase over the period considered, which can generally be ascribed to increased human pressure following population growth during the same period. Oscillations in the values obtained for fifty-year periods between the last half of the eighteenth century and the beginning of the twentieth suggest a strong connection with environmental and climatic factors. Increases or decreases in temperature seem to have a less marked and less direct effect on the values of grazing lands close to the upper limit of vegetation, while socio-economic and infrastructural signals impinge significantly on climate signals on the grazing lands at lower altitudes.

Keywords. Grazing lands, climate changes, Italian Alps.

JEL codes. Q54, Q15, Q51.

1. Introduction

1.1 Climate change and mountain agriculture

The consequences of ongoing climate change are the subject of an increasing number of scientific studies (IPCC, 2014). In particular, the interaction among climatic factors, agro-forestry systems and ecosystem productivity is currently being investigated using a variety of tools (Baglioni *et al.*, 2009; Bosello and Zhang, 2005; Roson, 2003; Solomon, 2007). The aim is generally to obtain an economic assessment of variations in well-being due to changes in the environments where agriculture is practiced (e.g., Palatnik and Nunes, 2010).

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ISSN 2280-6180 (print)
ISSN 2280-6172 (online)

In fact, in the Alps:

a) climate imposes very clear limitations on soil productivity[1];
b) the history of locations bears clear evidence of variations in climate[2];
c) for many centuries the development of communities has been strongly conditioned by agricultural productivity, which in turn is correlated with climate evolution (Mathieu, 2000, p.127).

In the southern Alps in particular, the traditional organisational structures of communities were such that private property was located near the villages and common pastures and meadows in the mountains (Raffaelli, 2005). This type of organisation reflected the fact that development of the local communities was to a large extent dependent on resources that could be generated locally. Unlike the fields close to the villages, pastures and woodlands could be exploited with low fixed investments and represented a reserve of resources that could be adjusted relatively quickly in the case of rapid increases or reductions in anthropic pressure.

From this perspective, the Alps are an ideal testing ground for measuring the economic consequences of climate change (Dearing 2006; Fraser 2009; Pfister and Brazdil 2006; Theurillat and Guisan, 2001).

Alpine pastures represent one of the most complex and interesting study cases. Forage productivity and quality in areas given over to pasture are closely linked to environmental factors, such as soil temperature, fertility and moisture (Baglioni, *et al.* 2009; Bosello and Zhang, 2005; Menzel and Fabian, 1999; Roson, 2003). Alpine pastures are characterized by a rapid growth in productivity in spring and summer followed by a period of gradual decline and decreasing quality. There is now an extensive body of scientific literature on the effects of temperature on productivity trends in Alpine pastures (Cavallero *et al.* 1992; Gusmeroli *et al.*, 2005; Orlandi *et al.*, 2004; Ziliotto and Scotton, 1993;), although there has not always been general consensus on the nature of the variability (Orlandi and Clementel, 2007). All of the studies agree, however, that pasture productivity is closely related to natural constraints and particularly to temperature variation, which, in the mountains more than anywhere else, has a direct effect on the vegetative cycle and the productivity of herbaceous vegetation. In other words, it seems to be clear that the productivity of mountain land varies over time in response to trends in temperature, with consequent fluctuations in its economic value.

In the Alps, spring temperature appears to be particularly important for total grass production. Indeed, it is well known that the growth of grass depends on accumulated temperature (day degrees); as a consequence, the spring temperature determines whether herds are taken up to the mountain pastures earlier or later (Gusmeroli et al, 2005). Summer temperature, on the other hand, appears to be less important in the Alps, so that the end of the grazing season, unlike the beginning, is traditionally set for a fixed date (20 September), at least in the area examined here (Bussolon, Martini, 2007). As far as precipitation is concerned, the climate regime in the entire Alpine area has a winter

[1] For example, the upper limit of tree growth (treeline) and the limit of cereal cultivation are usually defined by altitude. This is because, with the exception of specific local situations, average temperature and length of the growing season vary as a function of height above sea level.

[2] For example, toponomy still reflects situations arising as a consequence of the climate in the near or distant past. (Bussolon and Martini, 2007)

minimum (under the influence of the Russo-Siberian anticyclone in the cold months) followed by a maximum between spring and autumn. The study area in particular has a pre-Alpine type of climate regime with an autumnal maximum slightly higher than the spring maximum. Areas with a pre-Alpine climate are more influenced than others by their geographical proximity to the Po plain, which places few obstacles in the way of humid air masses. Spring precipitation in these areas is always abundant and, unlike in south-central Italy, no significant fluctuations are evident in the available historical series (Buffoni *et al.*, 2003). As a result, the precipitation regime has had less influence on the modifications in the seasonal productivity of pastures in these regions.

The mountains of the Italian pre-Alps studied here have been exploited at least since the sixteenth century. The pastures are part of a system based on vertical transhumance whereby livestock spend the summer on higher Alpine pastures (Salvador and Avanzini 2014). Against this background, the aim of this study is to investigate variations in pasture lease rents during the eighteenth and nineteenth centuries and how these correlate with climate changes. In analysing the relationship between climate variation and the value attributed to the pasture areas, account has been taken of natural and socio-economic factors, which may be summarised as follows: a) climate changes and, in particular, variations in spring temperatures; b) population evolution in pastoral communities.

Regarding the former issue, given that climate variability influences pasture productivity, as will be described later in greater detail, it may be considered a proxy for the potential volume of grass that the pastures produce. Regarding the latter issue, population evolution in an economic system that is closely dependent on local natural resources may be considered a proxy for anthropic pressure on the environment and hence for the demand for pasture with possible repercussions on the attributed value.

1.2 Climate and social well-being

As mountain areas have developed economically, especially in the periods prior to the industrial revolution and extensive migration, the link between resource availability and climate change has been crucial (Malanima, 2006), even though, as in other historical processes, altitude and environmental factors play a variable role (Mathieu, 2000, p.127). An increase or decrease in temperature of even a few tenths of a degree may result in an increase or decrease in resources, thereby contributing to capital gain or loss. Climate deterioration may lead to a shorter growing season with a consequent decrease in the value of pastures and radical changes in the exploitation of mountain areas, even over short periods of time (Bozhong, 1999). A decrease in temperature may give rise to a 10% reduction in calories per square centimetre of land, a shortening of the field pasture and forest vegetation growth period by three weeks, increased rainfall, changes in microbial activity in the soil and consequently its level of fertility, and a lowering by 150-200 metres of the altitude limit for growing cereals (Anfodillo, 2007).

According to some authors (e.g. Pfister, 2005), that contraction of pastureland in the European mountains at the height of the Little Ice Age (LIA - from the fourteenth to the late nineteenth century), restricted the prospects for pasturing animals. Lower forage yields also affected the quality and quantity of the milk produced. During the LIA weather and climate conditions were different from those prevailing in the preceding ‘Medieval

Warm Period' (from about 900 to the fourteenth century) and in the 'warm twentieth century'. The LIA was a simultaneous, world-wide phenomenon, although there were considerable regional and local variations. That epoch was the longest period of glacial expansion in the Alps for at least 3000 years. However, it should be stressed that the six centuries between 1300 and 1900 were not continuously cold. The cold phases were repeatedly interrupted by phases of 'average climate'. In some periods, e.g. from 1718 to 1730, the summer half-year was even somewhat warmer than the 'warm twentieth century'. It is in this context that Heinz Wanner coined the expression "Little Ice Age type events" (LIATE) to designate the three extensive advances known.

Many historians assume that the productivity of agriculture in the medieval and early modern periods depended only on the relative scarcity of two prime production factors: land and labour. The fundamental fact that agricultural output also depends on weather and climate has simply been ruled out. The most difficult study regards impacts and consequences. Having reconstructed past climate in the area of concern, biophysical impact studies may be carried out to identify the direct effect of climate anomalies on plants, domestic animals and disease vectors through study of their sensitivity to climate. Social impact assessment studies can then examine how biophysical impacts - i.e. the effects of climate anomalies on biota - propagate into the social and political system. This type of integrated approach, which would include the potential of people to adapt and adjust to climatic stress, reflects historical reality far better than a simple impact model and raises more fruitful research questions.

Pfister (2005) developed a climate impact model tailored to food production in the agrarian economies within the mixed economies of southern central Europe, where grain was the staple crop cultivated according to a three-field system in combination with dairy or wine production. It was found that a given set of specific sequences of weather spells over the agricultural year was likely to affect all sources of food, at the same time leaving little margin for substitution. This yielded a model of worst-case crop failure and, conversely, a year of plenty.

Livestock in traditional agriculture did not serve only the currently exclusive purpose of providing animal protein for human nutrition; instead, its vital role consisted in the multiple function of providing muscular power, manure and milk. Livestock provided large part of the required labour and enabled the active management of plant nutrients. The milk yields of cows and goats depended on the amount of the daily food ration available per animal and its nutrient content, mainly raw proteins. The amount of the feed ration varied according to the duration of the winter snow cover and autumn and spring temperatures.

In a frosty spring, the animals ran out of feed, as happened in 1688 in the example provided by Einsiedeln (Pfister, 2007). The longer the famine lasted, the longer it took for the animals to recover and resume their usual level of milk production. A long wet spell during the hay harvest in July and early August could reduce the raw protein content of the hay by as much as two-thirds, causing the cows to cease producing milk during the subsequent winter.

Most importantly, the simultaneous occurrence of rainy autumns, cold springs and wet mid-summers in successive years had a cumulative impact on agricultural production. This combination of seasonal patterns contributed largely to triggering extensive advances of the glaciers. Chilly springs and rainy mid-summers have been shown to be the most common climatic elements during the Little Ice Age, even though they were not causally related.

This economically adverse combination of climatic patterns is labelled "Little Ice Age-type Impacts" (LIATIMP). The biophysical climate's impacts in terms of the duration of cold spells and wetness in particular phases of the year may be relatively similar without being fully identical. Human responses to such impacts, on the other hand, often differ over time; and these differences may form the basis of in-depth studies on changing vulnerabilities.

At the same time, complex interactions with environmental changes compounded by socio-economic factors may eventually lead to a loss or decrease in the value of the asset (Gellrich *et al.*, 2007; Irwin and Geoghegan, 2001; Paavola and Fraser, 2011) and the associated rental fee. An example found throughout the southern Trentino region in the Italian Alps is the contrast between changes in the value of privately-owned agricultural land over time and the large tracts of forest and pasture assets managed by local communities. The former were subject to extensive fragmentation with a gradual reduction and dispersion of agricultural land; but the latter, because they had a fixed land area (the pastures in particular), made long-term management of the resources possible.

2. Materials and methods

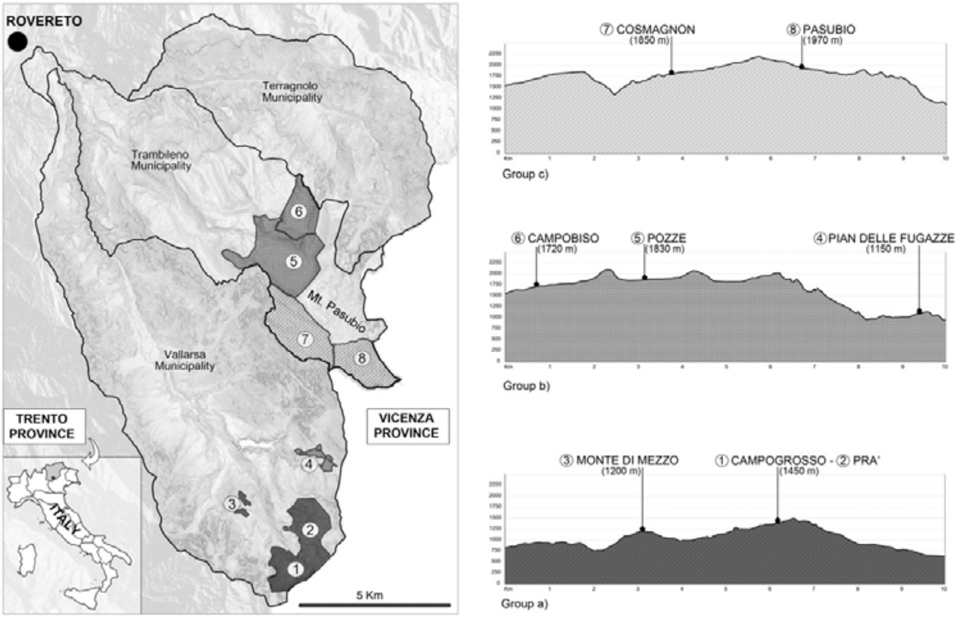
2.1 The study area

The pastures studied for this paper are located on the Pasubio massif and its surrounding areas (Fig. 1). The Pasubio is an extensive plateau in the southeast of the Trentino region (northern Italy) at a height of between 1500 m and 2000 m and confined by two deep valleys. The summit area is a wide plateau from which radiate a series of small valleys cutting deep into the slopes. The geological structure of the massif has given rise to the development of surface karst landforms where water drains deep into the mountain, leaving the summit land arid and feeding large springs at lower altitudes. In phytoclimatic terms the area is classifiable as pre-Alpine - moist temperate.

2.2 Temperature variability in the Alps

Very few quantitative reconstructions of climate variability in the Alps over the last millennium have been made. High-resolution reconstructions for the pre-instrumental period are based on documentary reports (Behringer, 2013; Lutherbacher *et al.*, 2004; Pflister, 2005, 2007), geochemical data (stable oxygen isotopes), physical data (annual growth rate of stalagmite laminae; Frisia *et al.*, 2007; Mangini *et al.*, 2005; Smith *et al.*, 2006), and temperature profiles measured along deep perforations (Pasquale *et al.*, 2003). Representative results can be expected from trees at the Alpine timberline, where the temperature during the short vegetative period controls the growth rate. Utilizing ring-width series measured with string instruments, several authors have developed a consistent, spatially-resolvable network of summer temperature-sensitive chronologies for high elevations in Central Europe for at least the last 500 years (Wilson *et al.*, 2005). A com-

Figure 1. The Pasubio area is in southern Trentino (Italy). The mountain pastures studied, higlighted in grey, occupy the central part of the Pasubio massif and the southermost part of the Vallarsa valley. (1 Campogrosso; 2 Pra; 3 Monte di Mezzo; 4 Pian delle Fugazze; 5 Pozze; 6 Campobiso; 7 Cosmagnon; 8 Pasubio).



mon temperature signal across the Alps has allowed regional reconstructions to be made of mean April–September temperatures (1650–1987) from ring-width (RW) and density (MXD) records using nested principal component regression models (Wilson *et al.* 2005).

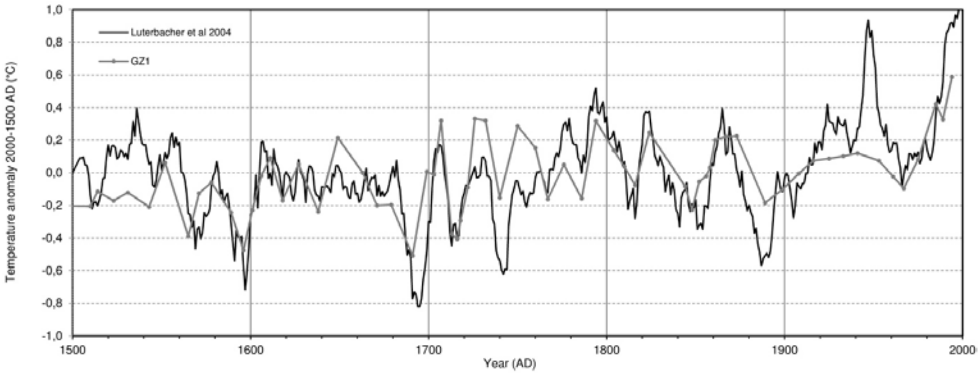
Calibration of paleo-climatic series with instrumental series is based on the assumption that the climate in the last millennium was characterized by modes of variability similar to those in the instrumental period. While this assumption may not be entirely correct, we can be reassured by the fact that all of the series now available display comparable low and high frequency variations. In fact, a comparison of temperature proxy reconstructions for the Alpine region highlights periods of synchronous warm and cold periods in the records (Mann *et al.* 2000; Pauling *et al.* 2003; Luterbacher *et al.* 2004, Wilson *et al.* 2004).

These variations can be adjusted to local contexts where the micro-climate or altimetric conditions diverge from the Alpine reference conditions.

2.3 The climate in the Pasubio massif in the last thousand years

Located at an altitude of 1025 m in the central Pasubio, the Cogola di Giazzera is a large cave with concretions that have been the subject of recent palaeo-climatic studies (Frisia *et al.*, 2007). Analysis of a stalagmite in this cave using the U/Th dating technique, micro-crystal analysis, and oxygen and carbon stable isotope ratios (284 samples) has made it possible to reconstruct the curve of local thermal anomaly over the last 4500 years.

Figure 2. Comparison of reconstructed temperature anomalies for the Pasubio (GZ1) (from Miorandi *et al.*, 2007) and for the Alps (from Lutherbacher *et al.*, 2004) over the past 500 years.



The isotopic series derived from the stalagmite's most recent concretions (U1), dated from 1060 ± 70 AD to today, had an average resolution of seven years. The isotopic series was synchronised with the Milan series (1750-1998) (Maugeri and Nanni, 1998) and with reconstruction of temperatures in Europe and the Alps from dendrocronological, instrumental and historical data (Mann and Jones, 2003; Lutherbacher *et al.*, 2004; Bohm et al 2001; Briffa et al 1998) (Fig. 2). The coefficient of correlation between the Giazzera and Luterbacher reconstructions of temperature anomalies was good ($r^2 = 0.77$).

For the purposes of the research reported in this article, we needed to be able to correlate the average temperature of the reference periods with those used to determine the rents for Alpine pastures in the study area. Because the leases were renewable every five years and the rent was correlated with this time frame, it was necessary to have temperature data on a scale of at least five years. The Giazzera dataset has a resolution of seven years, and Lutherbacher's (2004) series, having a resolution on an annual and seasonal scale, perfectly suited with the purposes of our analysis. Therefore, having confirmed the positive correlation between the temperature anomaly series reconstructed for the Pasubio and those available for Europe and the Alps (Frisia, 2007; Frisia *et al.*, 2007), Lutherbacher *et al.*'s (2004) annual thermometric data were adopted in the analysis.

2.4 Historical data

2.4.1 The social context: public good and private good

Except for the brief period of Napoleonic rule, from the second decade of the sixteenth century onwards few alterations were made to the political administration of the area, which was part of the Habsburgs' Tyrolean domains. With the demise of the feudal system in the eighteenth century, local communities gained possession of most of the mountain land and managed them by leasing pastures to local and non-local breeders (Salvador and Avanzini, 2014).

At the beginning of the eighteenth century, grazing land was the property of the community (now the district council) of Vallarsa, which every five years leased them by public auction to the highest bidder. The rental contracts contained clauses that remained substantially unchanged over time and were the same for all pastures in the same period. In this respect, changes in the rent values assigned to Alpine pastures are good indicators of climate changes. The fact that the extent of land[3] and its ownership do not change in part removes several socio-economic variables from the diachronic evaluation of their values.[4]

During the period considered, the population of the area increased in line with that of the entire Alpine region (Bussolon, Martini, 2007). In the area examined, between the eighteenth and nineteenth centuries the number of inhabitants grew, albeit more slowly than in the nearby plain. In order to increase food resources to feed the larger population there was a rise in the number of livestock raised and therefore an increased demand for pastures, with a consequent linear increase in their average value.

2.4.2 Source of economic data

The historical archives[5] of the administrative districts of the area under study contain the 'Auction Deeds' and the corresponding 'Auction Tenders' for grazing lands since the seventeenth century. They record the conditions on which the district council leased each grazing pasture, the price the tenant had to pay annually to the district council and any additional sums due, which in the eighteenth century would become a fixed fee for maintenance of the pastureland.

From the eighteenth century onwards (the first rental agreement examined here is dated 1719) the Vallarsa district council kept specific records of mountain leases with documentation of the costs and auction conditions. In the eighteenth century, the grazing lands were allocated in the autumn of the year preceding the start of grazing, although the auction for the five-year period 1774-1778 took place in the autumn two years previously (October 1772) and became the rule for successive decades. This gave the tenant who had won the auction sufficient time to procure cattle, hire a cheese maker and shepherds, procure all the cheese making equipment, ensure that the buildings (farmhouse and cheesemaking outbuilding) and infrastructures (roads, watering holes) were in good condition and, if necessary, carry out repairs.

From 1810, the auction deed also specified the reserve price (usually the rent from the previous five years) and by how much each bidder was willing to raise the starting price. When the reserve price was considered too high for that year, the auction was cancelled and another took place with a lower starting price.

The year of the auction, regardless of whether it took place one or two years prior to the start of the lease, was therefore taken into consideration in analysing the comparison with the standard thermometric series.

The price from 1719 to 1773 is given in trons, and after that in florins (1 florin = 5

[3] The actual extent of the pasturelands may well have varied as a result of tree clearance, or, in other periods, tree encroachment. However, while it is true that the areas cannot be measured with any certainty, it is also true that these changes to the grazing lands have no significant bearing on the analysis that follows.

[4] The Alpine pastures are not privately owned but are instead the property of the district council, which means no variables associated with land division and change of ownership need be considered. (Bussolon and Martini, 2007).

[5] The Trento State Archive, the Rovereto District Archive and the Vallarsa District Archive were consulted.

trons). In the nineteenth century, the price was given in various currencies: Tyrolean florins, Imperial florins and common florins (100 Viennese florins = 105 Tyrolean florins = 120 Imperial florins = 125 common florins). To overcome currency conversion problems, prices have been converted to silver equivalents, *i.e.* the actual amount of silver (in grams) contained in the coins in every year under study. Information regarding the various currencies is taken from Pribram (1938).[6]

It has been necessary to use silver as the numeric value because it is practically impossible to reconstruct a historical series of the prices of the products of livestock raising to which the analysis refers. The chosen indicator allows at least reduced instability, which happens to be rather substantial in some of the periods under study. A similar solution has already been adopted by other scholars (Allen, 2001). It goes without saying that such an indicator does not resolve the issue of silver's actual purchasing power. Nonetheless, no significant variation in silver's actual purchasing power has been recorded in the area under study (Bonoldi *et al.* 2018).

2.5 Analysis

2.5.1 Rents for pastures from the eighteenth to nineteenth centuries and the relationship with changes in climate.

Until the mid-twentieth century, land values and pasture rents were directly related to the productivity of the mountain. Therefore, to investigate the relationships between them, we compared the values of the pastures with environmental drivers in the study area.

This analysis took account only of those grazing lands for which there is a sufficient continuity of information on rents for the period 1719-1880. We also selected pastures used mainly for grazing cattle and which were not subject to any change of use during the period considered.[7] In addition, periods of evident socio-economic and/or political instability (such as the Napoleonic rule from 1800 to 1815) were excluded from the comparison, and any sums due in addition to the rents as a result of improvements to and work carried out on the buildings or pastures during the period under investigation were removed.

The grazing lands examined fell into three groups: a) Campogrosso/Monte di Mezzo/Pra, average altitude 1350-1400 m (low altitude); b) Pozze/Campobiso/Pian delle Fugazze, average altitude 1550-1600 m[8] (medium altitude); and c) Cosmagnon/Pasubio, average altitude 1900 m (high altitude).

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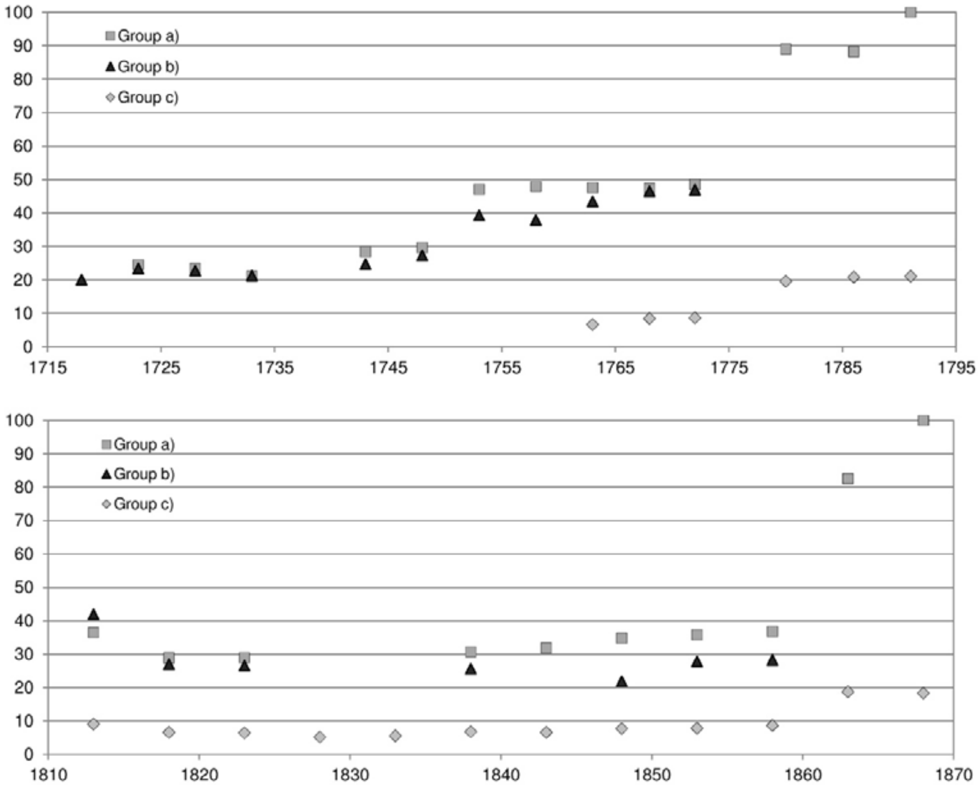
[6] Given the length of the period considered, use of a deflector in order to express the variables considered in terms of purchasing power would be desirable. Unfortunately, the available statistics do not allow even approximate estimates of this indicator to be made.

[7] Because of the scarcity of hay fields from the beginning of the twentieth century and the need for hay to feed livestock during winter, several pastures neighbouring Vallarsa were leased for haymaking and were only partly utilised for grazing. These were allocated directly (without public auction), although the contract was still for five years and the price in some cases did not change for as much as 30-35 years.

[8] We also had to consider the grazing lands at Passo Pian delle Fugazze (altitude 1100 m to 1300 m) as they were often leased together with those of Pozze/Campobiso. However, as they comprised only less than one fifth of the total area leased, these grazing lands should not greatly impinge on the following analysis. The Pozze/Campobiso pastures cover around 250 ha, those of Passo Pian delle Fugazze around 30 ha. The relationship between the sizes of the two areas remained more or less constant throughout the period considered.

Figure 3. Variations in rent values of the three groups of grazing lands between 1715 and 1850 normalised and expessed in silver grams.



Preliminary analysis of the variations in rent values (with all prices converted to florins) shows that they gradually increased over the course of the period studied as a consequence of the increase in demographic pressure, as can be seen from the following graph (Fig. 3).

Furthermore, comparison with the climate curve (Fig. 2) is highly consistent with the trend of rising average temperatures and hence with the presumed improvement in mountain weather conditions following the negative peak of the 1740s.

From the beginning of the period analysed, higher values were assigned to the grazing lands below 1500 metres, these being rich pastures at lower altitudes with relatively easy access, a reasonably assured supply of water and relatively speedy connections to the towns in the valley.[9] The grazing lands located at higher altitudes (group c) have poorer pastures and structural conditions that remained unchanged over time, and their rent values do not significantly increase.

At the turn of 1740, there was a drop in the value of the pastures for which data are available (a and b), possibly as a result of the marked fall in average temperatures over this

[9] A new road was constructed in 1823 giving better access to the area where all the grazing lands are located, which may have something to do with the greater value assigned to them between 1825 and 1839.

period (Fig. 2). A second, clear drop in the rent values of all the grazing lands (a, b and c) occurs between 1820 and 1845, followed by a marked rise in the next three five-year periods. This appears to coincide with the cold phase documented in the Alps between 1820 and 1840 (Büntgen *et al.*, 2006; Leonelli *et al.*, 2012; Rea *et al.* 2003), followed by a rapid rise in average temperatures from the 1850s onwards.

Differences in rent according to temperature and altitude may be understood in light of the differential rent concept defined by Ricardo (1821) and reinterpreted by, among others, Quadrio Curzio (1998).[10] Temperature and altitude are, in fact, the original natural factors influencing rents and therefore income.

In the case of grazing, as with many agricultural crops, productivity depends on natural factors and on permanent or temporary improvements resulting from human activities.

During the period considered, characterized by few technological innovations, temporary improvements linked to the use of production aids, such as fertilizers, seeds, etc., were almost non-existent. Even management organizational models remained more or less the same, as evidenced by the invariance of the conditions that applied to the tenant.

However, permanent improvements were effective, resulting in deforestation and clearing of the land occupied by the less steep woodlands. As a result of the increasing need for pastures, from the sixteenth and seventeenth centuries (Salvador and Avanzini, 2014) woods located at increasingly lower altitudes were ceded to grazing areas. The initial investment in deforestation increased, the lower the altitude.[11] These deforestation activities can be treated as investments and are considered fully amortized, given the period examined in this study.

Soils at lower altitudes are more productive and can be more easily associated with permanent housing.

In this framework, the annuity of a pasture in the period examined (i.e., in the absence of technological innovations and in an essentially closed market) will necessarily tend to increase in the presence of increasing human pressure. This will lead, as Ricardian theory suggests, to less fertile lands being cultivated and to an increase in the income from those already in use.[12]

2.5.2 Econometric analysis

To examine the available data in detail, a multiple regression analysis was conducted to identify the types of links between the variables that we considered important: the dependent variable being pastures' rent value[13] and the independent variables being temperature and population.[14] As already mentioned, to overcome problems resulting from the use of different currencies, we used silver equivalents of their values.[15]

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[10] The best-known reference is P. Sraffa (1925), but Keynes (1936) also worked on the problem.

[11] At lower altitudes, the forests are bushier with trees of larger diameter.

[12] Some pastures utilized in the nineteenth century were abandoned in a later period due to low fertility.

[13] During the period under examination the pastures' rent value in Campogrosso, Prà and Monte di Mezzo (Group a) varied between 25.258 and 8490.830 silver grams; pastures in Pozze, Campobiso, Pian delle Fugazze (Group b) yielded a rent between 24.175 and 3561.084 silver grams; Pasubio and Cosmagnon (Group c) between 7.998 and 1587.12 silver grams.

[14] In the period under study, population varied between 1394 and 3206 inhabitants.

[15] Other explanatory variables might be of some interest, e.g. the overall economic trend and farms' structure,

Population pressure was examined by taking information on the population residing in the Vallarsa district as a proxy.[16]

Regarding temperature, we decided to employ average values[17] for the spring immediately preceding the auction. As reported in the introduction, the spring/early summer temperature is crucial for grass growth and hence for determining the productivity of an Alpine pasture (Cavallero *et al.*, 1992). The nutrients contained in the soil are the most critical factors influencing the level of grass output and growth, although this also depends to some extent on precipitation patterns: too much precipitation, particularly during autumn and winter, reduces the content of calcium, phosphates and nitrogen in the soil.

Sequences of wet years had a cumulative impact, although temperature, according to results obtained by agronomists, has far more to do with mobilizing nitrogen from the soil than was previously believed (Bengston, 2004). Since temperature trends are spatially far more uniform than rainfall patterns, we may conclude that yields tend to react in a similar way within large regions.

Detailed analysis of the temperatures reconstructed by Lutherbacher *et al.* (2004) also reveals a high correlation between average spring temperature and average annual temperature (correlation coefficient 0.61) (Fig. 4). Furthermore, the use of constructed variables, such as moving averages and weighted moving averages of spring temperatures for the three years preceding the year of the auction, did not produce results significantly different to those obtained using simple average spring temperatures (c.c. 0.64 for moving averages, c.c. 0.82 for weighted moving averages).

The results of the preliminary analysis suggested using the average spring temperature of the year of auction, which has a greater influence than the average temperature of the previous years on the amount of grass in the pastures in the year of auction and ultimately on the bidding.

3. Results

3.1 Data elaboration.

An initial analysis was performed treating all the available information (59) as panel data (Greene, 2008). As the panel regression did not involve a significant increase in the explanatory capacity of the model, we estimated an ordinary least square regression on the entire set of available data. In this case, we used a double-log functional form of the following type[18]:

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but statistical information is not available to add such dimensions in the model. Given the specific situation we can nonetheless suggest that the effect of economic growth is to a certain extent captured by the population variable. In a closed economy, population growth is only possible when a larger amount of resources becomes available (Malthus 1798). The farms' structure does not change significantly in the period under examination (Bussolon and Martini, 2007). Given this specific context, we believe that, altogether, the lack of availability of further variables does not invalidate the main conclusions of the study.

[16] Missing observations for the years of interest were interpolated using linear regression.

[17] During the period under study, the average spring temperature was between 5.895 and 8.133 degrees Celsius (°C).

[18] We used a log-log formula to reduce the influence of the different rent values of the grazing lands. This functional form smooths the rent value differences.

Figure 4. Average annual temperature versus average spring temperature in the period analysed (from Lutherbacher et al. 2004).

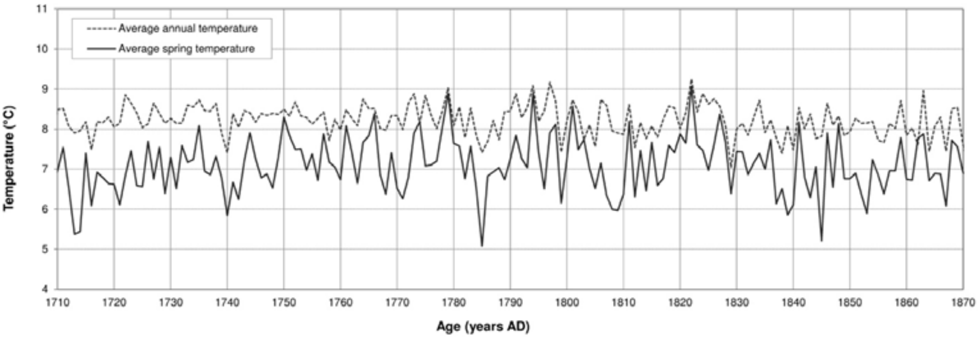

Table 1. Estimated results for all the mountain pastures

	Panel estimation
Population	+8.461 ***
Average spring temperature (degrees centigrade)	+2.783 **
Dummy variable for grazing lands at medium altitude	+1.634 ***
Dummy variable for grazing lands at lower altitude	+1.759 ***
Constant	-66.731 ***
r^2	0.896
adr^2	0.889
Number of observations	59

* Significant at 10% significance level, ** significant at 5% significance level, *** significant at 1% significance level.

LN(AR)[19] = f (LN(Pop), LN(S_temp), D_1, D_2

The estimated results are presented in Table 1.

We can note that all the estimates are significantly different from zero at least at the 0.05 value. Estimated coefficients confirm that average spring temperature and population positively affect the rent values of the grazing lands. Moreover, the lower the altitude of the grazing land, the higher is its rent value.

Given this relevant effect of altitude, we deemed useful to estimate separated functions for the three different groups of mountain pastures. Despite the small number of observations for each area examined, this exercise allows highlighting the role of population and temperature as a function of altitude.

In this case, it seems appropriate to introduce a new dummy variable for the grazing

[19] LN(AR) = logarithm of annual rent expressed in silver, LN(Pop) = logarithm of population, LN (S_temp) = logartihm of average spring temperature, D1 Dummy variable for grazing lands at medium altitude, D2 Dummy variable for grazing lands at lower altitude.

Table 2. Estimation results for three different groups of mountain pastures.

	Group (a) (low altitude)	Group (b) (medium altitude)	Group (c) (high altitude)
Population	+4.34 ***	+1.87 ***	+1.22 ***
Average spring temperature (degrees centigrade)	+798.21 **	+309.31	+199.43 *
Dummy variable for years after 1752	+1746.42 **		+418.86 **
Constant	-14554.24 ***	-5296.81 **	-4187.87 ***
r^2	0.80	0.77	0.82
adr^2	0.77	0.74	0.77
Number of observations	23	18	18

lands located on the border with the nearby Veneto region (group a, c), assuming a value of zero up to 1752 and one over the following years. This is to account for the fact that the borders were definitively fixed in 1752, thus putting an end to a series of incursions and acts of intimidation that had made the mountain unsafe for use in previous years.[20]

The estimated equations using the least squares method were as follows[21]:

AR[22] = f(Pop, S_temp, D)

Most estimates are significantly different from zero at least at the 0.10 value, except for average spring temperature for group (b). Estimated coefficients confirm a strong effect of human pressure due to population growth on rent values for each group of grazing lands. Interestingly, this effect is decreasing as moving from grazing lands at lower altitude towards grazing lands at higher altitudes, confirming the Ricardian assumptions. The same trend emerges for average spring temperature, which exerts the greatest effect on rent values for grazing land at lower altitudes, while for group (b) and group (c) the effect is lower.

In order to highlight the different sensitivity of rents to variations in spring temperature and changes in the size of the population we can calculate elasticities. The elasticity of rent to population indicates the average amount by which the rent varies as a response to a change in the population. The elasticity of rent with respect to temperature indicates the average amount by which the rent varies as a response to change of 1 degree Celsius in spring temperature. The elasticities of rent are presented in Table 3. Calculating these elasticities on regression results of Table 1 (all the grazing lands considered together) we obtain 0.70 for the elasticity with respect to population and 7.73 for the elasticity with

[20] The Campogrosso/Prà/Monte di Mezzo and Cosmagnon/Pasubio pastures are located on the border with the Veneto region. Until 1752 this border was not clearly defined and as a result animals might be found grazing in a neighbouring property, thus provoking punitive raids which included the animals' seizure, the burning of farmhouses and so on, and the beginning of lengthy controversies. With the Rovereto treaty (1752) the borders were precisely drawn and guarded, and there was a considerable increase in the rent values as a consequence of the greater security.

[21] Since there were no structural differences (e.g. in altitude) within the three groups identified for mountain pastures and their rents, we preferred to use a linear functional form.

[22] AR = annual rent

Table 3. Estimated rental price elasticities.

	Elasticity with respect to population	Elasticity with respect to temperature[a]
Overall elasticity	0.70	7.73
Group (a) (Campogrosso, Prà, Monte di Mezzo)	3.118	187.493
Group (b) (Pozze, Campobiso, Pian delle Fugazze)	0.830	36.735
Group (c) (Pasubio, Cosmagnon)	0.236	14.213

[a] In thousandths of a degree Celsius.

respect to temperature. This indicates that rents are inelastic with respect to an increase in population but are very elastic in response to an increase in average spring temperature.

The elasticities calculated for the three different groups confirm a different sensitivity of rents according to altitude. It appears as evident that changes in temperature have a much stronger impact on the amount of rent charged than changes in population.

The elasticity of rents with respect to population is high (3.118) for grazing lands located at low altitude but is inelastic for grazing land at medium (0.830) and higher altitude (0.236). We can therefore draw the conclusion that a change in human pressure has graver consequences for the grazing lands at low altitude than for those at higher altitudes. This is explained by the fact that it makes sense to make the best possible use of the lower grazing lands in the area under study given that they are, on the one hand, closer to the towns and villages and, on the other hand, adjacent to the tree line and can be "extended" by encroaching on the woods and forests. In contrast, there is no possibility of extending the pastures at the highest grazing lands, which in all probability are affected by the situation in the pastures at lower altitudes.[23]

The sensitivity of rent values to changes in spring temperature follows a similar pattern, even with a different order of magnitude.[24] The elasticity to spring temperature is very high for grazing lands at low altitude while it is lower for grazing lands at medium altitude and even lower for land located at higher altitude. This can be explained in part by the fact that even small increases in spring temperatures can give rise to longer pasturing periods in the low grazing lands, while the grazing period in the high pastures is much more constant.

4. Concluding remarks

Research conducted on the values of mountain pastures in the Pasubio estimated from the rents charged for them over a two-hundred-year period show that variations in these values are related to natural and anthropogenic drivers to varying extents depending on historical period and altitude.

[23] It should also be remembered that only pastures located above the tree line were at first utilised, and it was only later that pastures were created at lower altitudes by clearing the less steep woodland areas.

[24] The different ranges of variation of the two variables (low for temperature, high for population), rather than their different orders of magnitude should be taken into account when interpreting the high values for elasticity.

Oscillations in the values for 5-year periods between the last half of the eighteenth century and the beginning of the twentieth century suggest a strong connection with environmental and climatic factors.

Increases or decreases in temperature appear to have a less marked and less direct effect on the values of grazing lands close to the upper limit of vegetation, while, in addition to the climate signal, socio-economic and infrastructural signals impinge significantly on the grazing lands at lower altitudes.

If we consider that the value of the rent is an estimate of income and therefore of the utility of the "land productive factor" within the production process, we may draw some general considerations from this survey.

In particular, an interesting observation is that increasing population and temperature have the same influence in increasing the yield, independently of altitude.

For both the variables, the values of the rents for land located at a lower altitude - generally more fertile - have an elasticity approximately 13 times greater than that of land at a higher altitude. This means that human pressure and more favourable climatic conditions lead to significantly intensified pastoral activity in the fertile areas, while the income of marginal land is less affected by these changes. This finding is counterintuitive because people are generally inclined to believe that higher temperatures should favour pastures at high altitude because they should supposedly become more fertile. This apparent contradiction can nonetheless be explained with reference to the ricardian theory of rent. Our research supports what David Ricardo, at the dawn of economic science, had guessed. This contribution to the validity of the ricardian theory of rent is even more interesting given the long time interval considered and the relative small number of situations where this theory can actually be tested. Within agricultural production, only pastures have undergone no significant technological transformation over time.

The analysis partly suffers from the lack of consistent statistical data: given the length of the period under study, the elaboration could not always be conducted on homogeneous information. More precisely, the absence of a reliable indicator to convert the rent value into actual purchasing power can lead to a distortion in the estimates provided. Nonetheless, the elaboration carried out, if confirmed by other surveys, can provide a solid basis for appropriate measures of agricultural policy and land management adapted to ongoing climate changes.

5. Funding

This study is part of the Project ARMO - Archeologia del paesaggio montano: reti insediative e paleoambienti nelle Prealpi trentine" funded by MUSE - Science Museum (Trento) and the Department of Economics and Management of Trento University.

6. Conflict of Interest

The authors declare that they have no conflict of interest.

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