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Collapse of the Douro region's wine industry in 1756?

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Work in progress

Abstract

In the North of Portugal, the hills surrounding the Douro river, which flows into the Atlantic Ocean just after passing the cities Vila Nova de Gaia and Oporto, make up the Douro region. This region hosts the vineyards of the Portuguese Douro and Port wines.

In this paper we characterize the Douro region's wine industry in the early 1750s as a market for Lemons. In September 1756 the Portuguese government started regulating the production and sales of wine. Without this intervention or any other institution reducing the asymmetry between consumers and sellers of wine this industry could have collapsed or moved to production and sales of wines of the lowest quality only.

We evaluate this possibility by using data on wine exports from Oporto until 1756 to forecast wine exports for the period 1757 to 1776. We interpret these forecasts as the amount of wine which would have been exported without a remedy for the Lemon problem in the Douro region's wine industry.

We find declining but positive export forecasts during 1757-1776. This suggests that bad wines would have driven the good wines out of the Douro region without the wine industry ceasing to exist.

Keywords: Lemons market, forecasting, 18th century, wine, exports, Douro region, Portugal, England

JEL-Code: D82, C53, L66

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Introduction

In the North of Portugal, the hills surrounding the Douro river, which flows into the Atlantic Ocean just after passing the cities Vila Nova de Gaia and Oporto, make up the Douro region. This region hosts the vineyards of the Portuguese Douro and Port wines.

These wines, as any wine, are complex goods and without experience most consumers only know its quality after buying and drinking them. Wine sellers generally know more than consumers about the quality of their wines. What helps better informing consumers informed about the quality of wines they may buy, are labels on wine bottles indicating grape types, regional denomination, knowing whether regulators check a wine's quality and wine experts testing, rating or writing about wines. Technically, these practices reduce the information asymmetry between suppliers and consumers of wine.

Such provision of wine information to consumers did not exist around the turn of the 17th century when the Douro region's wine industry took off after a mix of sequential wars, peace Treaties and tax policies. That is, in those days consumers of wines from the Douro region, which were mostly English, only learned about the quality of the wine after drinking it.

Historical evidence shows that during the early 1700s the Douro region's wine industry experienced decades of growth. However, it found itself during the early 1750s with practices involving the addition of low quality grapes or of wines from other regions to its wines. It also faced a large drop in exports because consumers refrained from buying and complained about the quality of the sold wine. In September 1756 the Portuguese government started regulating wines in the Douro region.

With adverse selection affecting the industry the evidence suggests the Douro region witnessed the transformation of its wine industry into a market for Lemons as introduced by Akerlof (1970).[1] Without reducing the gap between sellers and consumers in information about quality, such a market may end up only providing wines of the lowest quality or even ceasing to exist.

Both historians and authors of the wine trade indicate that the wine industry in the Douro region was about to collapse before its regulation in 1756.[2] This implies that sales beyond that year would disappear absent regulation (or any other change). In this paper we evaluate whether the wine industry in the Douro region was indeed heading towards a collapse in 1756.

For this purpose, we use information on the exports of wine from Oporto from 1714 to 1756 and extrapolate their values to the years beyond 1756. If we find them trending towards zero

1 Using the automobile market as an example Akerlof (1970) explained that bad cars may drive out good cars from the market because they sell at the same price and consumers cannot tell the difference between a good car and a bad car.

2 For example, in his book on the politics of wine in Great Britain, Ludington (2013) notes "*In fact, the port wine industry almost collapsed in the 1750s*". See Ludington (2013), p145.

after 1756 then this supports the hypothesis that the wine industry was collapsing.[3]

We use statistical ARIMA models and exponential smoothing techniques for extrapolating the export values beyond 1756. Our results show that exports of wines from Oporto would have declined after 1756, *ceteris paribus*. The statistical uncertainty of this result suggests we cannot rule out increasing exports. This appears unlikely though given the evidence on adverse selection in the industry and the apparent willingness of English wine consumers to switch away from wine of the Douro region at that time.

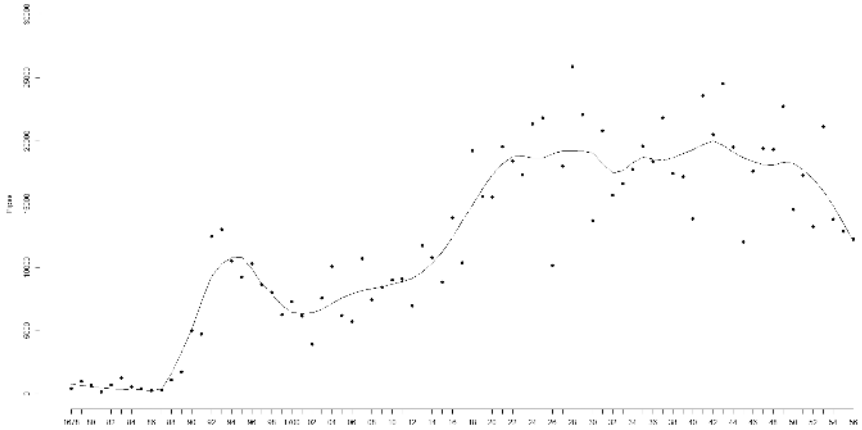
This paper has the following structure. Section 1 shows and describes the evolution of wine exports from Oporto in the period 1678-1756. Section 2 shows that the Douro region's wine industry shows the characteristics of a market for Lemons in the early 1750s. Section 3 forecasts wine exports from Oporto and assesses whether the Douro region's wine industry escaped from a near-collapse in 1756. Section 4 discusses the results.

3 Early empirical work on the Lemon problem includes Bond (1982, 1984) and Pratt and Hofer (1984). Bond (1982) tests whether bad trucks drive out good trucks in the pick-up truck market after observing that the lemons model predicts that owners of high maintenance trucks may be more likely to sell their truck than owners of low maintenance trucks if buyers cannot verify maintenance requirements. Pratt and Hofer (1984) refined Bond's analysis by taking into account the cost of maintenance and comparing maintenance requirements within the same period between sold trucks and unsold trucks held by their owners. Bond (1984) comments on their refinement and finds evidence of the Lemons problem for old trucks.

1. Exports of wine from the Douro region: 1678-1756

Wines from the Douro region found their way to other countries via Oporto.[4] This section describes the evolution of wine exports from Oporto during the period 1678-1756.[5] [6] Figure 1 shows the evolution of exports of wine from Oporto measured in pipes.[7]

Figure 1: Wine exports from Oporto: 1678-1756



Notes: The curved line is an estimated locally weighted regression curve.
Source: Andrade Martins (1990).

4 The supply chain of wine from the Douro region in the 17th and 18th centuries summarizes as follows. Wine growers grew their wines on the interior hills surrounding the Douro river. Wine transport took place over the Douro river to the shippers in Vila Nova da Gaia and Oporto close to the Atlantic Ocean. The shippers arranged export to England where merchants imported the wine and arranged further distribution of wine to the consumers.

5 The first mention of wine exports from the Douro region appears to date back to 1675. It concerns export of wine to the Dutch Republic. Also, the 1678 customs register in England shows evidence of wine from the Douro region imported into England. See Moreira da Fonseca et al. (1987).

6 During this period most of the wine exports from Oporto went to England. No information on the share of total wine exports which went to England appears available for this period. However, given the interest and involvement of the English in the development of the wine industry in the Douro region it is likely that by far most of the wine exports from the Douro region went to England. Andrade Martins (1990) notes that no information distinguishing exports to England from total exports are available until 1776. For 1776 she notes that 21937 out of a total export of 22620 pipes (97 percent) were exports to England.

7 The volume of a pipe is 550 liters. We obtained the data from Andrade Martins (1990). There is some evidence of wine fraud during the first three to four decades in Figure 1. This means not all wine exports from Oporto concerned wine from the Douro region for the early decades. Annex 1 discusses the data and wine fraud in more detail.

To facilitate its discussion we added an estimated non-linear trend to Figure 1.[8] Figure 1 shows small export volumes from 1678 onwards and a jump after 1688 which reached a peak in 1694. Exports then drop in 1700 to a level still higher than any level of annual exports before 1690.

This period coincides with a war between France and England allied with the Dutch Republic which broke out in 1688 and ended in 1697. This war reduced trade between French and Anglo-Dutch merchants because England prohibited imports of French wine from 1690 to 1696. This embargo induced English merchants to switch trading French wines to Portuguese wines. As a result, the Douro region also saw an increasing cultivation of vineyards which coincided with strong population growth at the end of the 17th century.[9]

The wine exports continued increasing after 1701 when the War of the Spanish Succession broke out between France and England allied with the Dutch Republic. France blocked England (and the Dutch Republic) from trading with Spain in 1702 facilitating wine consumers in England to switch from Spanish wines to Portuguese wines.

In 1703 England and Portugal closed a commercial agreement which was part of the Methuen Treaty. This agreement allowed Portugal to export its wines to England at a duty equal to two thirds of the duty which England charged for French wines. In exchange, Portugal removed the duty on cloth exports from England to Portugal. This agreement has been important for developing the Port wine industry although some argue it did not have a direct effect on English wine imports from the Douro region.[10]

Between 1700 and 1714 exports grew about 48% from 7287 to 10757 pipes. This growth accelerated after 1714 when the War of the Spanish Succession officially ended with the Treaty of Utrecht.[11] In 1726, exports appear exceptionally low. The year after, in 1727, shippers organized themselves and founded an association to represent their interests.[12] Exports were higher than 25000 pipes in 1728.

Figure 1 further shows that, on average, exports increased between 1732 and 1744 with peaks in 1742 and 1744. From 1744 onwards, exports started to decline and we observe a strong drop of about 46 percent from 22738 pipes in 1749 to 12211 pipes in 1756.

Ludington (2013) describes the situation in the Douro region's wine industry early 1750s as a "*classic scenario*" in which "*increased demand led to increased production, much in the form of inferior, adulterated, or non-genuine wines. This, in turn, led to a decline in overall quality and eventually decreased demand.*"[13] His characterization is much in line with the Lemons problem introduced by Akerlof (1970).

2. Problems with wine quality and regulation in 1756

Wine is an experience good because its composition is complex and its characteristics can only be verified after tasting it. Sellers of wine usually know more about the characteristics of wine than consumers of wine. This difference in knowledge about a wine's quality may lead sellers to sell wines of lower quality as a higher quality wine. Buyers will usually know a wine's quality only after purchase. Akerlof (1970) presents the first formal analysis addressing the consequences of an information asymmetry between sellers and buyers and introduces the market for Lemons.[14]

Market for Lemons

Akerlof (1970) investigates transactions between buyers of used cars who have less information about the quality of a car than selling owners of cars. A buyer may end up with a bad car (a lemon) as a result of the asymmetry between buyers and seller of used cars. He shows that in such a situation it is possible that no transactions take place even if prices exist at which buyers and consumers are willing to trade.

Using his analysis Akerlof comments that the costs of dishonest sales practices not only consist of the amount by which the buyer is cheated but to a larger extent of the loss incurred from driving legitimate business out of existence. In addition, he identifies dishonest business as a serious problem in less developed countries and notes evidence of a larger variation in product quality in underdeveloped areas than in more developed areas. These observations fittingly describe the Douro region's wine industry in the early 1750s.

8 We used locally weighted regression to fit the non-linear trend line (see, for example, Cleveland and Loader (1996)). Assuming a (local) Gaussian parametric family, we considered fifteen combinations varying in bandwidth 0.2, 0.4, 0.6, 0.8 and 1 and polynomial degree (0,1 or 2) and inspected their residuals visually. Our preferred specification has bandwidth 0.2 and polynomial degree 2. Figure 4 in Annex 2 shows its residuals.

9 See Moreira da Fonseca et al. (1987).

10 Boxer (1969) notes that the Methuen Treaty merely confirmed Portugal's' preferential treatment by England in the wine trade which started in 1690 and that the sweet wines of Lisbon benefited probably more from this Treaty than did the wines from the Douro close to Porto. Moreira da Fonseca et al. (1987) indicate that the Treaty's reduction of export duties on Portuguese wines to two thirds of the export duties on French wines did not significantly increase exports of Port wine to England.

11 The commercial arrangement between England and Portugal on wine duties favorable to Portugal was a subject of contention and heavily debated during the negotiations which led to this Treaty. Despite objections from France, Portugal maintained its favorable position in wine exports versus France and could continue exporting wine at a lower price relative to France. See Ludington (2013), Chapter 4.

12 See Andrade Martins (1990), p290.

13 See Ludington (2013), p149.

14 Lemons problem, principle, respectively, model are different ways to refer to the information asymmetry problem Akerlof describes.

The Douro region's wine industry in the 1756

Figure 1 reflects that the Douro region's wine industry of wine was in development during the first half of the 18th century. It was not a mature industry in which the matter on how to produce a quality wine was settled. The asymmetries in knowledge about the quality of wine between sellers of wine and consumers of wine were likely to be stronger than they are now. For example, these days labels on wine bottles, wine brands, tastings, courses, degrees and experts help reducing the asymmetry between sellers' and buyers' knowledge about wine quality.

There is evidence that dishonest practices in the wine trade took place which plausibly led to the decrease in wine exports we observe during the 1750s in Figure 1. Around 1730 the wines of the Douro region had a good reputation. Evidence on complaints about the wines' quality dates back to the early 1730s. For example, Fisher (1971) cites an English merchant in 1734 and the English Lisbon Consul in 1742 complaining about wines shipped from Oporto containing too much brandy.[15] Fonseca et al. (1987) note that "*[...] quality suffered; and malicious reports helped to hasten disrepute*".[16] Mason (2011) observes that "*By the 1730s sugar was also being added and baga came to be used to bolster both the colour and flavour of wines overstretched by poor-quality spirit. Worse, still wine from Spain [...] and raisin wines mixed with British spirits extracted from malt were passed off or blended in to Port*".[17]

In 1754 English shippers tried to improve the worsening situation in the wine industry by sending a letter with instructions to wine growers and their brokers seeking improvement of the quality of wines.[18] This letter starts with: *"So deplorable is the state to which the trade in wines of the Douro is reduced, that its present appearance exhibits the symptoms of speedy and total ruin: this compels us to be attentive that every means be adopted to restore it, if possible to its reputation"*. In their response to this letter the wine brokers agree with this assessment stating that: *"The deplorable state to which the wine trade is reduced (as you have justly lamented) [...]"*.[19]

In 1755 influential participants in the Douro region's wine industry met to discuss their concerns about the industry's future and how to address the problems it faced. This provided a basis for the wine regulation which eventually took place in September 1756.[20]

These pieces of evidence strongly point to a Lemons problem in the Douro region's wine industry. However, it does not rule out that changes in income or prices or a negative demand shock can explain the drop in wine exports we observe in Figure 1 between 1750 and 1756.

15 See Fisher (1971), footnote 5, p83.

16 See Moreira da Fonseca et al. (1987), p19.

17 Mason (2011), p11.

18 In the letter they blame the wine growers and their brokers for providing low quality wine. This letter is reprinted in an essay written by an anonymous Portuguese author in 1824. See [A Portuguese] (1824).

19 In their response to the shippers' letter they blame the shippers for demanding large(r) quantities of wine at the cost of low(er) wine quality. This letter is reprinted in an essay written by an anonymous Portuguese author in 1824. See [A Portuguese] (1824).

20 See Moreira da Fonseca et al. (1987).

As explanations for this drop they appear less plausible than the market for Lemons' theory though. For example, during this period, England experienced a period of population growth suggesting that if an income effect was present it would have increased exports to England.[21] Also, during the period 1703-1756, the only change in duties on the imports of wines into England took place in 1745 which was five years before 1750.[22] Although England was involved in wars during 1739-1748, a general negative demand shock does not seem to have affected England's demand for wine. We find that total imports of wine into England increased by 0.9 percent between the seven-years-periods 1743-1749 and 1750-1756.[23]

In sum, a market for Lemons appears to be the most credible explanation for the strong drop in wine exports from Oporto between 1750 and 1756.

Regulation in 1756

Akerlof (1970) notes that in markets subject to information asymmetries numerous institutions can arise to reduce uncertainties about product quality mentioning government intervention, product guarantees, branding, retail chains and licensing practices.

What actually happened in September 1756 with the Douro region's wine industry was that the Portuguese government set up a state monopoly regulating the production and sales of wine from the Douro region.[24] Under this government it introduced legislation until August 1776 controlling prices, quality and it demarcated the area in which grapes could be grown to produce wine which could be sold as wine from the Douro region.

Akerlof's analysis suggests that without this intervention or any other remedy for the Lemons problem the industry could have disappeared or ended up selling wines of the lowest quality only. We explore this possibility and assess whether wine exports from the Douro region would have continued declining after 1756 in that situation.

21 See the 1754 letter to the brokers by the shippers (footnote 18) which mentions: *"[...] although the increased population of England is a just ground for expecting a larger consumption, yet the demand has gradually decreased"*

22 The duties for French, Portuguese, Spanish and Rhenish wines increased from 54.5, 25, 26 and 30.5 to 62.5, 29, 30 and 34.5, respectively (see Ludington (2013), p262-63). These changes imply that compared to Portuguese wines, the duties on French, Spanish and Rhenish wines became 1.1, 0.5 and 2.5 percent lower.

23 Using data from Schumpeter (1960) we find total wine imports into Great-Britain equal to 106508 and 105521 tuns for 1743-1749 and 1750-1756, respectively (a tun equals 2 pipes or 1100 liters). While total imports appear constant between the two periods, the drop in imports from Portuguese wines between these two periods appears to be matched by an increase of wine imported from Spain (whose war with England ended in 1748). A permanent shift in consumer taste away from Portuguese wine seems unlikely as well. In his book Ludington (2013) describes how the taste for wine shifted from French wines to Portuguese wines in the first half of the 17th century.

24 The Portuguese government founded the "Companhia Geral de Agricultura das Vinhas do Alto Douro" on 10 September 1756. The wine industry's concerns about its future was not the only reasons for its foundation. Portugal experienced decreasing income from Brazil after decreases in the production of gold in Brazil and the depletion of mineral resources in Brazil. In addition, the great Lisbon earthquake in 1755 led to the loss of about forty thousands of lives and left Lisbon destroyed, increased Portugal's expenses and further drained income. Also, a change of government took place in Portugal and Sebastião José de Carvalho e Melo, who was awarded the title Marques de Pombal later in 1770, became Prime Minister of Portugal in August 1756.

3. A near-collapse of the Douro region's wine industry in 1756?

Akerlof's analysis suggests that without the government's intervention in September 1756 or any other remedy for the Lemon problem in the Douro region's wine industry it could have disappeared or ended up selling wines of the lowest quality only. We evaluate this possibility by forecasting wine exports from Oporto for the period 1757-1776. We chose this period because in 1776 the Portuguese government which set up wine regulations in 1756 signed its last legislation regulating wines in the Douro region.

Forecasting wine exports from Oporto

To forecast exports we use univariate time-series techniques.[25] These techniques model time-series as a combination of predictable and unpredictable components and allow for extrapolating the predictable components into the future. Applying them allows us to predict exports beyond 1756 using information until 1756 only.

Empirical approach

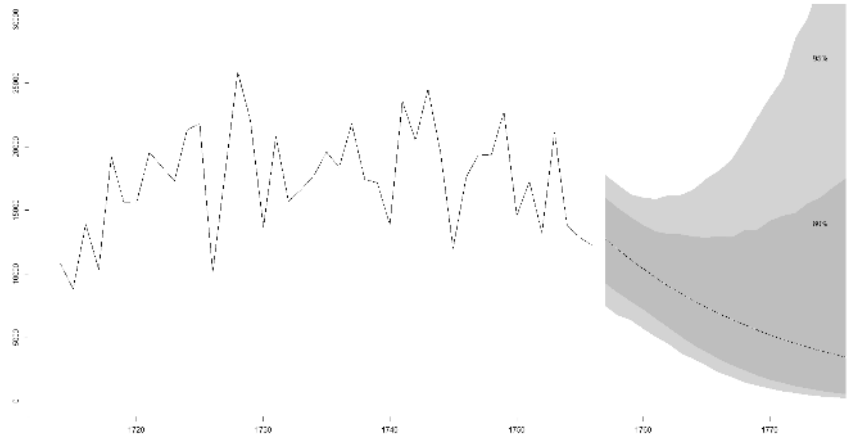
We use two different techniques: autoregressive integrated moving average ("ARIMA") and exponential smoothing methods. The ARIMA models model the statistical distribution of exports for each moment in time.[26] Exponential smoothing methods allow predicting the level of exports in a future year.[27] These methods decompose exports in three terms capturing a trend, seasonality and an error, respectively.

We estimate various ARIMA models and exponential trend smoothing models to forecast exports. To determine our preferred model we focus on how well they forecast exports for the period 1750-1756 if we re-estimate them using only data before the years we predict.[28] To measure the deviation of forecast values from actual values we calculate the mean absolute error ("MAE") and the root of the mean squared error ("RMSE"). A lower value of these measures indicates better forecast performance. Annex 3 explains further how we assess forecast accuracy.

Results

We estimated 12 models and find that the exponential smoothing model with a multiplicative error and trend is best in terms of forecasting accuracy.[29] We use this model to forecast export values for the period 1757-1776. Figure 2 shows them together with the actual export values for the period 1714-1756. The light and dark areas in Figure 2 show 95 and 80 percent forecast intervals, respectively.[30]

Figure 2: Actual wine exports from Oporto (1714-1756) and export forecasts for 1757-1776



Notes: (i) The solid and dashed line shows actual exports and export forecasts for the periods 1714-1756 and 1757-1776, respectively. (ii) The export forecasts are from an exponential smoothing method with a multiplicative error and a multiplicative trend. (iii) The light and dark grey areas show the 95 and 80 percent forecast intervals, respectively.

The solid line in Figure 2's grey area shows our export forecasts. It slopes downward and suggests exports would have declined in the absence of government intervention by regulating wines. It does not suggest that an immediate collapse of the industry would have occurred. Figure 2 suggests that in the absence of a remedy for the Lemon problem bad wines would have driven the good wines out of the Douro region.

25 A univariate time series technique exploits the information in the past of a single time series to extrapolate its values into the future.

26 Greene (2003) explains ARIMA models.

27 Hyndman et al. (2008) discuss exponential smoothing methods.

28 The traditional way in which we re-estimate the model for the period 1714-1749 and generate seven export forecasts for each of the seven years in the period 1750-1756. Another way is to do this on a rolling basis which means that we increase the estimation period 1714-1749 each time by a year and reduce the out-of-sample-forecast period 1750-1756 by a year. For a given model, this provides us with 28 forecasts for the period 1750-1756. We prefer this latter method to the traditional method. Annex 3 explains in more detail how we generate out-sample-forecasts in two ways for each model.

29 We estimated 4 ARIMA models and 12 exponential smoothing models. Annexes 4 and 5 discuss these models and presents their results. Of the ARIMA models the white noise model appears with the best forecast accuracy. Its in-sample performance does not differ much from the other three ARIMA models we consider. We rely on the time-series cross-validation method of assessing the model with the best forecast accuracy because it provides a more robust way to assess out-of-sample forecast performance than the traditional method. For a given model it re-estimates the model seven times (instead of one) and calculates in total 28 export forecasts. This compares with one re-estimation and seven export forecasts for the traditional method.

30 In principle, exponential smoothing methods provide a future prediction of exports and not a statistical distribution of exports for each moment in time. However, statistical state space models have been linked with exponential smoothing methods. This allows for the calculation of forecasting intervals measuring the statistical uncertainty of our export forecasts.

The light and dark grey areas in Figure 2 show the 95 and 80 percent forecast intervals, respectively. With probabilities 95 and 80 percent, these intervals contain the export values which would have appeared in the absence of the intervention, *ceteris paribus*.

They reflect the statistical uncertainty of our result and they become wider to more distant export forecasts are from 1756, the year of the last actual export value we used for our forecasts. They indicate that, with 95 percent (forecast) certainty, the export level in 1749 would not have been possible before 1769.

The forecast intervals also suggest that we cannot statistically rule out an increase in exports between 1757 and 1776. However, given the turbulent affairs in the Douro region's wine industry it is not clear how or what would have allowed exports to return to growing after 1756.

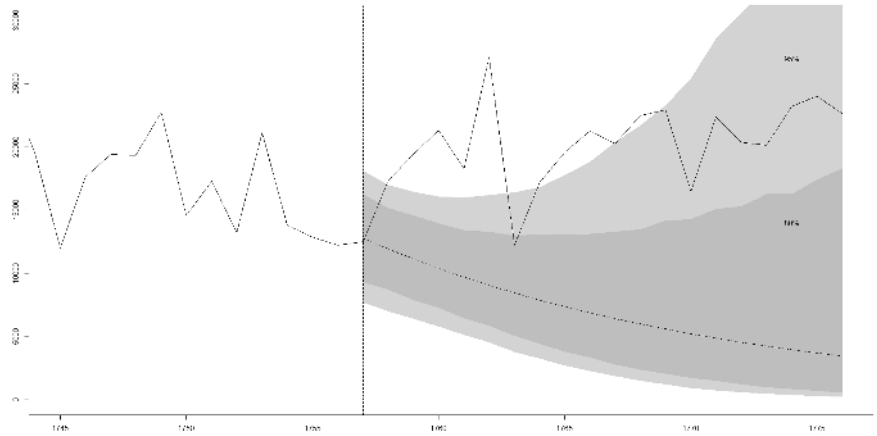
4. Discussion

Our forecasts suggest that the Douro region's wine industry was transforming into a low-quality wine industry by 1756. Statistically, they did not rule out the possibility of increasing exports after 1757 if the government would not have intervened by introducing wine regulations.

The trade and history literature considers this intervention as beneficiary for the Douro region's wine industry, at least in the short term.[31] This suggests it is unlikely that the actual export values after the intervention could have been obtained without any remedy for the Lemons problem in the Douro region's wine industry in 1756.

Figure 3 compares the hypothetical forecasts of Figure 2 with the actual export values. We have added actual export values for 1745-1756 to compare them with actual export values after the government intervened in 1756.

Figure 3: Actual wine exports from Oporto (1745-1776) and export forecasts for 1757-1776



Notes: (i) The downward sloping dashed line shows the export forecasts of our preferred model for 1757-1776. (ii) The solid line shows the actual exports. (iii) The vertical line shows 1757, the first year after wine regulations started. (iv) The light and dark grey areas show the 95 and 80 percent forecast intervals, respectively.

Figure 3 suggests that export levels would have been lower without the government's regulation of Port wine in 1756. Until 1769, most of the actual export levels lie above the upper-bound of the 95 percent forecast interval.[32] That indicates that it would have been

31 For example, see Mason (2011), p15, Moreira Fonseca (1987), p32, and Ludington (2013), p151, respectively.

32 Note that (i) forecast intervals become wider with the forecast horizon (twenty years in this case) and (ii) we

unlikely for exports to obtain those values in the absence of the intervention or any other remedy for the Lemons problem.[33]

Of interest is the question whether other remedies than the Portuguese government's intervention would have been able to restore the reputation of wines from the Douro region. The economic literature offers various suggestions to reduce the asymmetries between sellers and buyers of wine. We mentioned some of them in the introduction and in Section 2. While some of these remedies were not known then, it remains a question whether the course of events would have allowed their implementation if they would have been known.[34]

evaluated the out-of-sample forecast performance of our models for horizons that are at most 7 years (1750-1756).

33 According to the results, the probability that exports would have reached those levels in those years without any intervention is not larger than five percent.

34 See footnote 24 for the events which facilitated the introduction of wine regulations by founding a state monopoly.

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Annex 1: Data

Source

We use annual data measuring exports of wine from Oporto for the period 1678 to 1772. Our source is Andrade Martins (1990) who compares various historic sources on these exports to construct an annual time series of wine exports from Oporto. This appears to be the most extensive and recent source with data on exports of wine from Oporto in the 17th and 18th centuries.

We compared the data we use for our analysis from Andrade Martins (1990) with Forrester (1851) and Guerner (1808) who also show data on wine exports from Oporto. We find the data in large agreement with each other except for three years and have made one change for the year 1740.[35]

Andrade Martins (1990) notes that it is not strictly correct to interpret exports of wine from Oporto before 1778 as exports from Oporto to England or Great Britain (from 1707 onwards).[36] However, it appears to be a reasonable assumption given the important role England played in developing the wine industry in the Douro region. In addition, Andrade Martins (1990) finds wine imports into Great Britain from Oporto equal to 21937 pipes and wine exports from Oporto equal to 22620 pipes. This suggests about three percent of wine exports went to other destinations than Great Britain in 1776. It shows that in that year almost all exports from Oporto went to Great Britain.[37]

Sample period

There is evidence suggesting that statistics of wine exports from Oporto may not only include wines from the Douro region but also wine from other countries, in particular from France. Embargoes of 1678-1685 and 1690-1696 prohibiting imports of wine from France to England appear to have had the effect of fraud consisting of exporting French wine as if it were Portuguese wine.[38]

Ludington (2013) notes that French wine was channeled to England via Portugal in the years

35 In our data from Andrade Martins (1990) we changed the value of 18352 pipes for 1740 into 13352 pipes which Forrester (1850) and Guerner (1814) report for 1740. The reason for this change is that Andrade Martins (1990) notes that all the sources she considered show the same values for the years 1732 to 1776 (Andrade Martins (1990), footnote 4, p225). These sources include Forrester (1850) and Guerner (1814). We find two additional small differences in export values between Andrade Martins (1990), Forrester (1850) and Guerner (1814) for our sample period 1714-1776. The values Forrester (1850) and Guerner (1814) report are just 0.6 and 0.01 percent higher for the years 1716 and 1726, respectively. All other 60 years have the same values across the three sources.

36 See Andrade Martins (1990), p33.

37 No information appears available on exports of wine from Oporto to other countries than England before 1776. See Andrade Martins (1990), p225.

38 See footnote 16 of Andrade Martins (1990), p37.

1682, 1683 and 1685.[39] He observes that this practice still occurred during the second embargo of 1690-1696 but to a lesser extent and mentions the practice also for the period 1697-1702.[40]

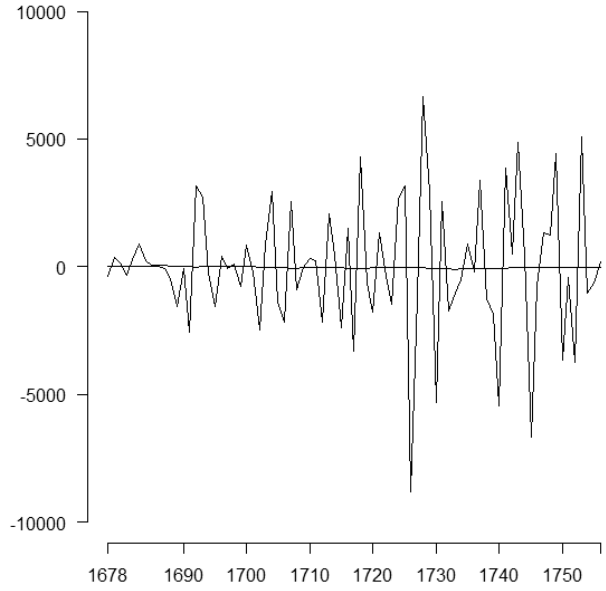
Further evidence by Ludington suggests that fraud may still have existed by 1706 as the municipality authorities of Bordeaux in France decided to carry out inspections in order to prevent such fraud. If these inspections had an immediate effect, 1707 would be a potential starting year for our analysis. However, Nye (2007) suggests fraud may have existed even after 1706.[41]

Given the evidence on fraud we use the years 1714 to 1756 for our analysis. In 1714 the War of the Spanish Succession officially ended with the Treaty of Utrecht marking the first year in which England was not at war with France since 1701.

39 Ludington (2013), p33 and pp39-41, respectively.
40 Ludington (2013), p36.
41 See Nye (2007), p41.

Annex 2: Residuals Figure 1

Figure 4: Residuals local regression curve of Figure 1



Notes: (i) The plot shows the residuals of a local weighted regression with bandwidth 0.2 and polynomial degree 2 assuming a (local) Gaussian parametric family. (ii) the approximate horizontal line at zero is a locally weighted regression fit to the residuals of the curve in Figure 1 with bandwidth 1/3, polynomial degree 1 and assuming a (local) Gaussian parametric family as in Cleveland and Loader (1996).

Annex 3: Forecasting

Out-of-sample forecasts

We estimate each model using data for 1714-1756. We generate out-of-sample forecasts of a model by re-estimating it with information for the period 1714-1749 and forecast the export values for each of the years in the period 1750-1756. This is the traditional method of generating out-of-sample forecasts. This provides us with seven forecast values for a given model.

In addition, we also use time series cross validation to assess the models' accuracy. This means that instead of re-estimating the model once, we re-estimate the model seven times each time adding a year to the estimation sample and reducing the test forecast period 1750-1756 by one year. Hence, we (1) re-estimate the model for 1698-1749 and forecast values for 1750-1756[42], (2) re-estimate the model for 1698-1750 and forecast values for 1751-1756, (3) re-estimate the model for 1698-1751 and forecast values for 1752-1756, etc. until we re-estimate the model for the seventh time using information for 1698-1755 and forecast the value for 1756.

This approach considers seven forecast periods 1750-1756, 1751-1756, 1752-1756, 1753-1756, 1754-1756, 1755-1756 and 1756 providing 7, 6, 5, 4, 3, 2 and 1 export forecasts, respectively. These add up to a total of 28 export forecasts to measure the accuracy of a model.

Forecast accuracy

To measure the deviation of forecast values from actual values we calculate the mean absolute error ("MAE") and the root of the mean squared error ("RMSE"). These are standard methods to assess forecast accuracy.

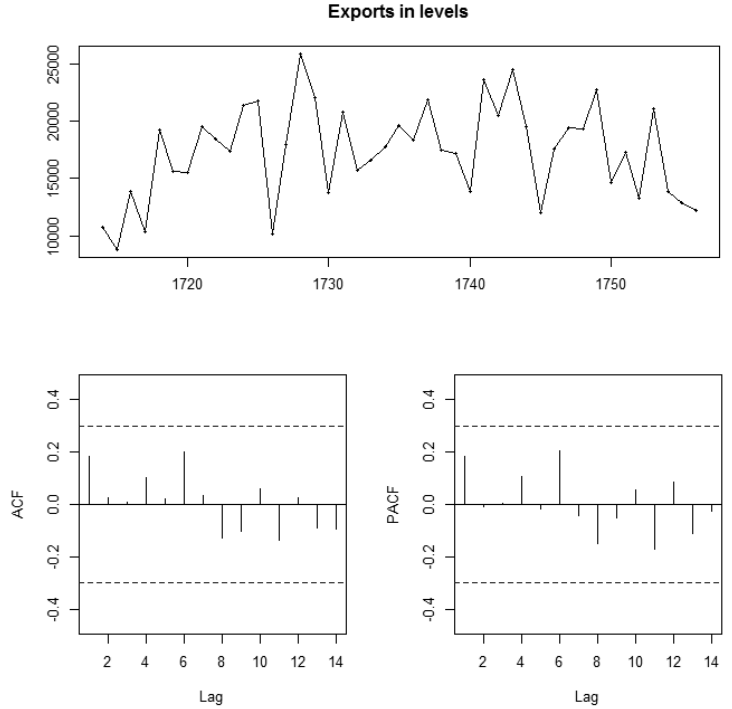
The MAE method calculates the absolute value of the difference between the export forecast and the actual export value for a given year and provides the average across all available 'forecast-actual' pairs. The RMSE method calculates the squared difference between the export forecast and the actual export value for a given year, takes the square root of the average across all available 'forecast-actual' pairs. The difference between the two methods is that the RMSE gives a higher weight to values with larger deviations between the forecast value and the actual value than the MAE method.

42 This first step is the same as the traditional method explained before.

Annex 4: ARIMA models

The estimation of ARIMA models requires exports to be stationary.[43] Figure 5 shows exports during 1714-1756 and its corresponding (partial) autocorrelation functions.

Figure 5: Exports and (partial) autocorrelation functions – 1714-1756



Notes: (i) ACF refers to the autocorrelation function which measures the relationship between exports and previous exports as a function of the lag in years. (ii) PACF refers to partial autocorrelation function which measures the relationship between exports and previous exports as a function of the lag in years without the effects of intervening lags. (iii) The dashed horizontal lines indicate critical values of the estimated correlations. If the correlations cross them then the correlation is statistically significant (at a 5 percent level of significance).

43 That is, exports behave consistent with a statistical distribution whose mean and variance do not change over time.

Figure 5 suggests exports behave according to a stationary process during 1714-1756.[44] The bottom of Figure 5 shows the autocorrelation function (ACF) and partial autocorrelation function of exports (PACF).

The dashed horizontal lines indicate critical values of the estimated correlations. If the correlations cross them, then the correlation is statistically significant (at a 5 percent level of significance). None of the estimated (partial) autocorrelations cross them suggesting that exports follow a white noise process. That is an ARIMA(0,0,0) may fit the export data well. We also consider the following alternative specifications: ARIMA(1,0,0)[45], ARIMA(0,0,1)[46] and ARIMA(1,0,1).

Table 1 shows the results.

Table 1: Results - ARIMA models: 1714-1756

	(1) White noise	(2) MA(1)	(3) AR(1)	(4) ARMA(1,1)
θ_1		0.183		-0.667
		(0.143)		(0.300)
θ_2				
Φ_1			0.198	0.827
			(0.156)	(0.261)
Φ_2				
constant	17344.9	17304.5	17278.2	16875.1
	(620.0)	(718.8)	(757.6)	(1324.7)
Log-likelihood	-418.4	-417.6	-417.6	-417.5
AIC	840.8	841.3	841.2	842.9
BIC	844.3	846.6	846.5	850.0
Q(3)	1.57 (p=0.666)	0.060 (p=0.972)	0.012 (p=0.994)	1.013 (p=0.314)
Q(6)	4.172 (p=0.653)	2.770 (p=0.735)	2.714 (p=0.744)	3.419 (p=0.490)
Q(10)	6.000 (p=0.816)	4.909 (p=842)	5.046 (p=0.830)	6.158 (p=0.630)

Notes: (i) Standard errors are reported in parentheses. (ii) AIC and BIC measure the (in-) sample fit of the models and refer to the Akaike and Bayes-Schwartz criterion, respectively. Lower values indicate better (in-) sample fits. (iii) Q(n) reports the Ljung-Box Q-statistics for autocorrelations of the n residuals in the estimated models.

Table 2 shows the out-of-sample performance for the different models in Table 1.

44 We also carried out statistical stationary tests. The augmented Dickey fuller test rejects the null hypothesis of a unit root while the KPSS test does not reject the null hypothesis of stationarity.

45 This is an autoregressive-model with one lag.

46 This is a moving-average-model with one lag.

Table 2: Forecast accuracy - ARIMA models

	Forecasts:	**Traditional**		**Cross-validation**	
Mode	Type	MAE	RMSE	MAE	RMSE
1	White noise	3403.5	3733.2	4197.6	4386.2
2	MA(1)	3258.9	3635.3	4242.5	4413.3
3	AR(1)	3888.0	4285.4	6107.4	6607.4
4	ARMA(1,1)	3867.2	4273.5	6224.1	6738.4

Notes: (i) Traditional refers to the traditional method of generating out-of-sample forecasts. Cross-validation refers to the time series cross-validation method to evaluate forecasts. (ii) MAE and RMSE refer to the mean-absolute-error and root-mean-squared-error calculation of forecast accuracy, respectively.

Table 2 shows that the moving average model has the lowest forecast errors for 1750-1756 according to the traditional method. The cross-validation method points to the white noise model as the one with the best out-of-sample forecast performance.

Annex 5: Exponential smoothing methods

We consider eight exponential exponential smoothing methods. Hyndman et al (2008) show how statistical state space models form the statistical theory behind exponential smoothing methods. They frame these models in terms of how they model (i) the error term (E), (ii) the trend term (T) and (iii) seasonality (S) and refer to them as ETS models. These models can be linear or non-linear which is different from ARIMA models which are linear.

We estimate eight ETS models. None of them assumes seasonality because we have annual data and Figure 1 does not suggest cyclical periods akin to seasonality. They vary in whether we assume the underlying ETS model has (i) an additive error or a multiplicative error, (ii) a trend or not and, if yes, whether the trend is damped or not. The exponential smoothing models we consider have an additive error and (1) no trend, (2) a linear trend or (3) a linear trend that can damp or they have a multiplicative error and (4) no trend, (5) a linear trend, (6) a linear trend that can damp, (7) a multiplicative trend or (8) a multiplicative trend that can damp.

Note that the first three models (1) to (3) are linear models, whereas the last five models (4) to (8) are non-linear.

It can be shown that the ARIMA(1,1,2), ARIMA(1,1,1), ARIMA(1,1,0), ARIMA(0,2,2), ARIMA(0,1,1) and random walk ARIMA(0,1,0) models are special cases of the linear exponential smoothing model (3). The (non-linear) models (4) to (8) which all have a multiplicative error do not have a nested ARIMA model representation (see, for example, Gardner (2006)).

Results

Table 3 shows the estimation results for the various exponential smoothing models.

Table 3: Results - exponential smoothing methods

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	AN	AA	AA_d	MN	MA	MA_d	MM	MM_d
smoothing								
α	0.186	0.133	0.045	0.204	0.109	0.026	0.120	0.089
β		0.114	0.025		0.109	0.026	0.120	0.089
Φ			0.900			0.890		0.874
Initial states								
l	14935.0	9397.1	9397.0	14944.8	9230.8	9397.1	9485.1	9486.4
b		1008.8	1139.7		1581.5	1493.8	1.138	1.169
sigma	4049.0	4015.3	3785.0	0.239	0.209	0.203	0.211	0.206
AIC	880.1	883.3	880.3	881.4	876.1	876.7	878.2	877.4
BIC	883.6	890.4	889.1	884.9	883.1	885.5	885.3	886.2

Table 4: Forecasting accuracy - exponential smoothing methods

				Forecasts:	Traditional		Cross-validation	
Model	Type	Error	Trend		MAE	RMSE	MAE	RMSE
1	AN	Additive	No		4876.4	5271.8	4661.7	4886.3
2	AA	Additive	Linear		5666.6	6325.8	4459.0	4829.3
3	AA_d	Additive	Linear, damped		5271.4	5748.7	5359.1	5715.3
4	MN	Multiplicative	No		4849.1	5240.0	4649.8	4872.8
5	MA	Multiplicative	Linear		4985.0	5401.7	2828.7	3464.5
6	MA_d	Multiplicative	Linear, damped		4985.0	5401.7	5256.3	5569.5
7	MM	Multiplicative	Multiplicative		4030.8	4254.9	2814.5	3233.7
8	MM_d	Multiplicative	Multiplicative, damped		4693.8	5061.2	5107.7	5398.0

Notes: (i) None of the models have a seasonal component. (ii) Traditional refers to the traditional method of generating out-of-sample forecasts. Cross-validation refers to the time series cross-validation method to evaluate forecasts. (iii) MAE and RMSE refer to the mean-absolute-error and root-mean-squared-error calculation of forecast accuracy,respectively.