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MEASURING THE ECONOMIC EFFECT OF GLOBAL WARMING ON VITICULTURE USING AUCTION, RETAIL AND WHOLESALE PRICES

Orley Ashenfelter
and Karl Storchmann

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Retail and Wholesale Prices.**

Orley Ashenfelter
Industrial Relations Section, Firestone Library
Princeton University
Princeton, New Jersey 08544-2098
Tel (609) 258-4040, Fax (609) 258-2907
email: c6789@princeton.edu

and

Karl Storchmann
Economics Department
New York University
19 W. 4th Street, 6FL
New York, NY 10012
Tel (212) 992-8083, Fax (212) 995-4186
email: karl.storchmann@nyu.edu

Abstract

In this paper we measure the effect of year to year changes in the weather on wine prices and winery revenue in the Mosel Valley in Germany in order to determine the effect that climate change is likely to have on the income of wine growers. A novel aspect of our analysis is that we compare the estimates based on auction, retail, and wholesale prices.

Although auction prices are based on actual transactions, they provide a thick market only for high quality, expensive wines and may overestimate climate's effect on farmer revenues. Wholesale prices, on the other hand, do provide broad coverage of all wines sold and probably come closest to representing the revenues of farmers. Overall, we estimate a 1°C increase in temperature would yield an increase in farmer revenue of about 30 percent.

Key words: wine, global warming, auction prices, retail prices, wholesale prices

1. Introduction

In this paper we assess the economic impact of global warming on viticulture in the Mosel valley of Germany. There are two features that are unique to the Mosel region. First, located between 49.61⁰ and 50.34⁰ latitude, all Mosel vineyards are situated near the far northern boundary for commercial grape growing. As a result, quality wine production in the Mosel valley depends on special site characteristics and favorable weather conditions to ensure winter survival and ripening (Ashenfelter and Storchmann, 2010). Thus wine prices, crop yields and wine quality are crucially dependent on weather and vary widely from year to year. Second, within the comparatively narrow Mosel valley, most vineyards are planted on steep slopes of rocky, relatively unfertile soil (mostly slate) that is inappropriate for crops other than vines. Therefore, given the limited possibilities of crop substitution or alternative land usages, temperature induced changes in viticulture directly reflect the economic impact of global warming in this part of Germany.

We use the so-called “Ricardian” approach applied by Mendelsohn, Nordhaus, and Shaw (1994) to the study of effects of climate change on agriculture. Their empirical research, based as it is on hedonic models from highly aggregated data, has been critiqued and extended to consider difficult issues of functional form and specification by Schlenker, Hanemann, and Fisher (2005 and 2006), and Deschênes and Greenstone (2007). These more recent studies generally find considerable heterogeneity in the expected effects of climate change. Depending on the region considered, climate change may lead to either positive or negative effects on land values, with considerable uncertainty about the aggregate effect. Our approach follows this more recent work by studying a very specific area and type of crop and by establishing the economic relation using time-series variation in the weather.

Particularly, we provide and compare the results of three models based on different price data, i.e., retail, wholesale and auction prices. The empirical results of our models are broadly similar and indicate that the vineyards of the Mosel Valley will increase in value under a scenario of global warming, and perhaps by a considerable amount. Vineyard and grape prices increase more than proportionally with greater ripeness, so that we estimate a 3°C increase in temperature would more than double the value of this vineyard area, while a 1°C increase would increase prices by more than 25 percent.

II. Data and Model

This analysis is aimed at analyzing the effect of year to year fluctuations in the weather on prices and profits of viticulture in the Mosel valley of Germany. Since, overall per hectare cost is independent of changes in temperature and precipitation (Ashenfelter and Storchmann, 2010) our study focuses on revenue and its components. In general, we examine per hectare revenue from 1997 to 2008 in each of the five viticultural districts (called *Bereich*) of the Mosel valley, the *Upper Mosel* (from Luxemburg to the City of Trier), the *Middle Mosel* (from Trier to the village of Pünderich), the *Lower Mosel* (from Zell to the Rhine River) and the two Mosel tributaries, the *Saar* and the *Ruwer Valley*.

Although revenue is the simple product of price and crop yield, there is an added complexity in the study of the prices of German wines that results from the way the wines are labeled and marketed. German wines are classified (and labeled) according to the natural sugar content of the unfermented grape must (freshly pressed grape juice) measured on the Oechsle scale.¹ In general, sweeter unfermented musts lead to higher alcohol volumes (and not necessarily sweeter wines), more aroma and thus higher quality. In ascending order, the quality levels and Oechsle thresholds for Mosel wines are *Quality Wine* (lowest quality category, no °Oe requirement), *Kabinett* (70°Oe), *Spätlese* (76°Oe), *Auslese* (83°Oe), *Beerenauslese (BA)* (110°Oe), *Eiswein*² (110°Oe), and *Trockenbeerenauslese (TBA)* (150°Oe). A primary quality distinction is that, with the exception of *Quality Wine*, it is illegal to add sugar to the must. As a result, wine prices are distinguished by the vineyard where the grapes are grown and by the quality level.

Although revenue per hectare data are not readily available, they can be computed by multiplying crop yield data by the average prices for each district and each wine quality level. Let R_{idt} , P_{idt} , and Q_{idt} denote per hectare revenue, price and quantity produced of wine quality level i in district d and at time t , then

$$(1) \quad R_{idt} = \sum_{i=1}^7 \sum_{d=1}^5 (P_{idt} \cdot Q_{idt}).$$

Total revenue in wine district d will be determined by prices and quantities produced in each quality category.

Wine production data by district and quality category for the years 1997 to 2008 were prepared and provided by the Statistical Office of the State of Rheinland-Pfalz and its agricultural commission (*Landwirtschaftskammer*).³ Detailed production data for the time period before 1997 are not available.

¹ Degrees Oechsle (°Oe) is used in Germany and Switzerland and denotes the specific weight of the must compared to the weight of water at a temperature of 20°C, while much of the English speaking world uses a measure called brix. One liter of water weighs 1000g, which equals zero degrees Oechsle. Accordingly, grape must with a mass of 1084 grams per liter has 84 °Oe. Since the mass difference between equivalent volumes of must and water is almost entirely due to the dissolved sugar in the must, degrees Oechsle measures the relative sweetness of the grape juice. Approximately, one brix is equal to one degree Oechsle divided by 4.35 (Peynaud, 1984).

² The quality category *Eiswein* has the same Oechsle requirement as *Beerenauslese* (i.e., 110°Oe). However, *Eiswein* grapes need to be harvested while frozen.

³ These data are available, by request, from the authors.

Wine prices by quality category and viticultural district are not readily available but can be computed drawing on various wine price data. We use three different sources, i.e., retail, wholesale and auction data, and generate quality and district specific wine prices and revenue data.

Each data set has advantages and disadvantages. A disadvantage of the retail and wholesale price data is that they refer to posted prices, which may not be transaction prices. An advantage of these data is that they cover a wide range of Mosel wine producers. The auction prices refer to actual transaction prices, but only a tiny fraction of the very finest Mosel wines are sold at auction. As a result, the auction prices may not be representative of the region more generally.

Our retail price data come from the 1994-2008 issues of the Gault Millau Wine Guide for Germany (Diel and Payne, 1994-2008). The wine guide provides detailed information about the wines' characteristics such as age, geographical origin (vineyard and wine district), and quality classification and the data permit us to calculate wine prices for each wine district and quality level accounting for other characteristics.

The wholesale price data come from the Mainz Wine Trade Fair (*Mainzer Weinbörse*). Once a year for two days, the fair showcases the wines of about 100 VDP estates.⁴ The fair is open to the wine trade only. Our dataset covers the fair years 1993 to 2001 and contains a total of 1063 wines from the Mosel wine region (Mainzer Weinbörse, 1993-2001).

Our auction price data come from the period 1981-2008 from the wine associations *VDP Grosser Ring*⁵ and *Bernkasteler Ring* (VDP Grosser Ring, 1992-2008; Bernkasteler Ring, 1981-2008). These groups of wineries have existed for more than 100 years and annually present and sell the latest vintage of their wines at the retail level. However, over the last 40 years, the character and role of their annual wine auctions has fundamentally changed. During the first decades after their establishment the two associations marketed the majority of their wines through auctions. Auctions were held twice a year, most wines were sold in 1000 liter barrels and wines offered comprised all categories of the quality spectrum with an emphasis on lower qualities.

⁴ In Germany, most high-quality wine producers are organized in the Association of German Quality Wine Estates (*Verband Deutscher Prädikatsweingüter VDP*). See also Schnabel and Storchmann (2010).

⁵ Data for *VDP Grosser Ring* were available only from 1992 on.

Now, each association holds only one auction per year; all offered wines are bottled and bulk wine (lower qualities sold in barrels) has not been put to auction since 1974. For instance, in 1954, the then 24 member wineries of the Bernkasteler Ring auctioned off a total of 447,700 bottle-equivalents of wine. The majority of these wines were below the *Spätlese* quality level and almost all were sold in bulk. In contrast, in 2008, the now 34 member wineries auctioned off a total of just 3,150 bottles, only 480 of which were below the *Spätlese* quality level. That is, while wine auctions in the Mosel valley may have been representative of the regional wine production at large for most of the past century, they now rather serve as a vehicle for showcasing a few high-quality wines. Our auction sample focuses almost exclusively on the upper end of the quality scale; only 0.13% of all wines auctioned off are *Quality Wines* (lowest quality category). In comparison, 74.1% of all wines produced are *Quality Wines* (see also Table 2).

Table 1 provides the descriptive statistics of the three price samples. It is apparent that the sample characteristics are largely different. While the average real wholesale price per 0.75 liter bottle equals €6.19 (\$8.04)⁶, this is €22.15 (\$28.80) and €77.32 (\$100.52) for the retail and auction samples, respectively. These differences are even larger for the maximum prices. While the maximum wholesale price equals €124.44 (\$161.77) the most expensive wine at auction costs €211.11 (\$5474.44). It is evident that the price differences are due to differences within each quality category as well as to the divergent structure of wines sold. Within each quality category, auction prices rank the highest while wholesale prices are the lowest. In addition, while the wholesale sample does not comprise any *Beerenauslese* and *Trockenbeerenauslese* wines, these quality categories constitute a substantial part of all wine sold at auctions.

⁶ Assuming an exchange rate of \$1.30/€

Table 1
Descriptive Statistics of Price Samples

	Mean	Minimum	Maximum	Std. Dev.	Observations
Retail					
All	22.05	2.21	543.81	40.58	6238
<i>Quality Wine</i>	6.24	2.21	25.44	3.83	850
<i>Kabinett</i>	5.96	2.83	20.73	1.92	1086
<i>Spätlese</i>	9.26	3.80	71.70	5.45	2006
<i>Auslese</i>	30.98	5.34	537.85	44.67	1785
<i>Eiswein</i>	84.19	16.16	311.38	44.78	242
<i>Beerenauslese</i>	90.41	24.35	543.81	65.45	187
<i>Trockenbeerenauslese</i>	179.26	34.51	414.93	84.27	81
Wholesale					
All	6.19	2.51	124.44	4.88	1063
<i>Quality Wine</i>	3.95	2.51	9.71	0.78	259
<i>Kabinett</i>	4.92	3.69	11.03	0.89	362
<i>Spätlese</i>	6.84	4.51	19.34	1.73	328
<i>Auslese</i>	12.51	7.08	40.10	5.53	112
<i>Eiswein</i>	124.44	124.44	124.44		1
<i>Beerenauslese</i>					0
<i>Trockenbeerenauslese</i>					0
Auction					
All	77.32	2.97	4222.11	264.55	2398
<i>Quality Wine</i>	8.15	7.92	8.35	0.22	3
<i>Kabinett</i>	5.84	2.97	42.22	4.04	269
<i>Spätlese</i>	12.16	3.88	343.60	16.52	759
<i>Auslese</i>	45.04	5.31	1968.50	88.13	1074
<i>Eiswein</i>	276.69	44.24	1427.17	267.06	96
<i>Beerenauslese</i>	281.22	29.57	4222.11	441.67	129
<i>Trockenbeerenauslese</i>	931.92	124.40	3939.96	968.88	68

Prices in €per 0.75 liter bottle.

Table 2
Percentage Shares by Wine Quality Category

	<i>Quality Wine</i>	<i>Kabinett</i>	<i>Spätlese</i>	<i>Auslese</i>	<i>Eiswein</i>	<i>Beerenauslese</i>	<i>Trockenbeerenauslese</i>
Retail	13.63	17.41	32.16	28.61	3.88	3.00	1.30
Wholesale	24.37	34.05	30.86	10.54	0.09	0.00	0.00
Auction	0.13	11.22	31.65	44.79	4.00	5.38	2.84
Production	74.11	6.90	12.65	6.19	0.04	0.11	0.00

Table 2 reports the quality category shares of each price sample in comparison to the actual wine production from 1997 to 2008. It is apparent that the auction price sample is not likely to represent the Mosel wine production as a whole. While more than 12% of all wines sold at auction are of *Eiswein*, *Beerenauslese* or *Trockenbeerenauslese* quality, this segment represents less than 0.2% of the overall production in the Mosel valley.

As we shall see, the response of prices to the average temperature during the growing season is very sensitive to the particular type of wine quality being studied, making it likely that these data may suffer from selection bias. In particular, since the prices of the higher quality wine types are much more responsive to temperature increases, the auction price data are likely to dramatically overstate the average effect of a temperature change on prices. Although we report the results using these data for completeness, we do not rely on them for our primary analysis.

Table 3
Descriptive Statistics of Exogenous Variables

	Mean	Maximum	Minimum	Std. Dev
Retail				
Temperature Growing Season (degree C°)	12.27	13.02	10.89	0.59
Rain Growing Season (mm)	4735.92	6988	2777	1222.05
Rain Winter (mm)	2000.17	3463	1198	682.85
Age (years)	1.12	3	1	0.33
Wholesale				
Temperature Growing Season (degree C°)	12.18	12.79	10.89	0.57
Rain Growing Season (mm)	4703.03	6988	2777	1108.96
Rain Winter (mm)	2036.08	3463	1198	807
Age (years)	1.17	8	1	0.58
Auction				
Temperature Growing Season (degree C°)	12.09	13.02	10.50	0.68
Rain Growing Season (mm)	4530.09	6988	2353	948.98
Rain Winter (mm)	1944.37	3463	616	591.76
Age (years)	2.08	80	1	3.99

Table 3 provides the descriptive statistics of the exogenous variables used for the three price models. For each sample, the difference between minimum and maximum growing season temperatures is well above 2 degree Celsius, a magnitude that equals the average expected warming for Europe for the next 90 years (Intergovernmental Panel on Climate Change, 2007).

III. Results

As originally shown by Ashenfelter and collaborators for the Bordeaux wine region, wine quality and price are highly depended on weather (Ashenfelter et al., 1995). In northern latitudes warmer and drier growing seasons are expected to lead to higher fruit quality. The precise relation varies with the grape type, but this relation has been quantified in many viticultural areas.⁷ Winter rainfall has also been shown to have a positive effect on fruit and wine quality, although this result has not been found for all the viticultural areas where it has been studied. Our primary interest is in the effect of temperature on vineyard profits, but to the extent that rainfall and temperatures are correlated it is essential to control for these other aspects of the weather in the regressions. Therefore, the weather variables we include in the regressions are (a) the average temperature over the growing season (*Temp Growing Season*), (b) the total rainfall in the growing season (*Rain Growing Season*), and (c) the total rainfall in the winter preceding the growing season (*Rain Winter*).

⁷ See, for example, Ashenfelter and Storchmann (2010), Ashenfelter (2008), Haeger and Storchmann (2006), Jones and Storchmann (2001) and Ashenfelter et al (1995) and Ashenfelter and Byron (1995).

Table 4
Weather and Wine Prices

	Dependent Variable		
	(1) ln(Retail Prices) ^{d)}	(2) ln(Wholesale Prices) ^{d)}	(3) ln(Auction Prices) ^{d)}
Constant	1.102*** (7.29)	1.347*** (10.09)	-1.926 (-46.71)
Growing Season Temp ^{a)}	0.042*** (2.86)	0.014 (1.15)	0.324*** (2.95)
TBA ^{e)*}	0.275** (59.14)		0.327*** (10.95)
Growing Season Temp ^{a)}			
BA ^{f)*}	0.217*** (68.76)		0.238*** (8.10)
Growing Season Temp ^{a)}			
Eiswein*	0.215*** (73.14)	0.284*** (18.14)	0.253*** (8.76)
Growing Season Temp ^{a)}			
Auslese*	0.110*** (55.28)	0.092*** (51.67)	0.075*** (2.59)
Growing Season Temp ^{a)}			
Spätlese*	0.037*** (24.35)	0.046*** (34.93)	0.002 (0.03)
Growing Season Temp ^{a)}			
Kabinett*	0.004*** (2.59)	0.020*** (15.59)	-0.041 (-1.44)
Growing Season Temp ^{a)}			
Middle Mosel*	0.003 (0.68)	-0.006* (-1.97)	0.010 (0.41)
Growing Season Temp ^{a)}			
Lower Mosel*	0.009** (2.21)		0.048 (1.85)
Growing Season Temp ^{a)}			
Saar*	0.019*** (4.81)	-0.013*** (-4.09)	0.036 (1.41)
Growing Season Temp ^{a)}			
Ruwer*	0.010*** (2.69)	0.004* (0.14)	0.029 (1.13)
Growing Season Temp ^{a)}			
Rain Winter ^{b)}	-0.001*** (-4.95)	0.014*** (3.59)	-0.002*** (-4.45)
Rain Growing Season ^{c)}	0.0002*** (2.57)	-0.0002 (-0.45)	0.001*** (5.26)
ln(age)	0.341*** (9.83)	-0.0002*** (-3.50)	-0.094 (-1.87)
R2	0.705	0.776	0.673
F statistic	1060.92***	331.80***	350.80***
n	6355	1063	2398

a) February to October, b) December to February, c) April to October d) in real prices., e) Trockenbeerenauslese, f) Beerenauslese; significance levels of 1% (***), 2% (**), 5% (*); Newey-West robust t-values in parentheses;

Columns (1) and (2) of Table 4 contain the results of the price equation drawing on retail and wholesale prices, respectively.⁸ Since wines are labeled by their (1) quality level (in descending order of quality *Trockenbeerenauslese (TBA)*, *Beerenauslese (BA)*, *Eiswein*, *Auslese*, *Spätlese*, *Kabinett*, *Quality Wine*), and (2) their regions, we have interacted the temperature variable with each of these categories in order to produce

⁸ Note that the wholesale price sample does neither contain prices for wines from the Lower Mosel district nor prices for *Beerenauslese* and *Trockenbeerenauslese* qualities.

quality- and region-specific temperature coefficient estimates. *Quality Wine* from the *Upper Mosel* serves as reference. It is apparent that warmer weather has a significantly positive effect on prices. Higher wine qualities, such as *Trockenbeerenauslese*, *Beerenauslese* and *Eiswein* benefit from a warmer growing season more than lower qualities. In addition, the marginal effect of temperature increases is the highest in the districts of the Mosel tributaries *Saar* and *Ruwer*.

Aside from weather, a wine's quality is determined by its age. We included a variable *age* which denotes a wine's age when it was offered. Most age-worthy wines increase in value as they grow older, but most lower quality table wines do not. The overall effect, therefore, is unclear

The results in column (3) indicate that auction prices are considerably more responsive to temperature changes than retail and wholesale prices, as we expected.

However, the use of these generated price data to compute revenue data, which are then again regressed on weather data, might predetermine the weather-sensitivity of wine revenues. We thus generate district and quality-level specific price data by referring to the sugar content of the grape must (degree Oechsle) instead of weather. The results of these models are similar to the weather-related regressions and are reported in Table 5.

To obtain an overall estimate of temperatures on gross revenue per hectare we must combine the information on crop yields by region and quality level with the average prices by region and quality level. Figure 1 shows the fraction of wines of *Auslese* and higher qualities as a part of the entire production in selected districts and the Mosel region as a whole over the period 1997-2008. The Ruwer region exhibits the highest variance with a range from 1% in 1998 to 52% in 2003. Figure 1 also shows the average growing season temperature over the same period, and it is apparent that there is greater production of high quality wines in warmer years. The result is that (1) increases in temperatures result in increases in wine prices within each quality segment and (2) increases in temperatures also shift the quality structure of wines produced upward.

Table 5
Degree Oechsle and Wine Prices

	Dependent Variable		
	(1) ln(Retail Prices) ^{d)}	(2) ln(Wholesale Prices) ^{d)}	(3) ln(Auction Prices) ^{d)}
Constant	0.267 (1.58)	1.328*** (8.07)	-2.762*** (-8.24)
Degree Oechsle (Sugar Content of Grape Juice)	0.017*** (7.82)	0.002 (0.81)	0.064*** (15.24)
TBA ^{e)}	3.355*** (59.55)		4.407*** (12.18)
BA ^{f)}	2.643*** (66.41)		3.130*** (8.70)
Eiswein	2.623*** (75.41)	3.452*** (18.12)	3.420*** (9.69)
Auslese	1.336*** (55.55)	1.130*** (51.21)	1.079*** (3.06)
Spätlese	0.440*** (24.02)	0.558*** (34.54)	0.223 (0.63)
Kabinett	0.043*** (2.34)	0.240*** (15.43)	-0.194 (-0.55)
Middle Mosel	0.039 (0.05)	-0.082** (-2.08)	-0.075 (-0.22)
Lower Mosel	0.013*** (2.54)		0.464 (1.33)
Saar	0.241*** (5.01)	-0.168*** (-4.23)	0.266 (0.79)
Ruwer	0.123*** (2.67)	0.162*** (3.41)	0.152 (0.45)
ln(age)	0.324*** (9.65)	-0.110*** (-5.38)	-0.289 (-6.54)
R2	0.705	0.774	0.679
F statistic	1240.79***	399.80***	420/72***
n	6355	1063	2395 ^{g)}

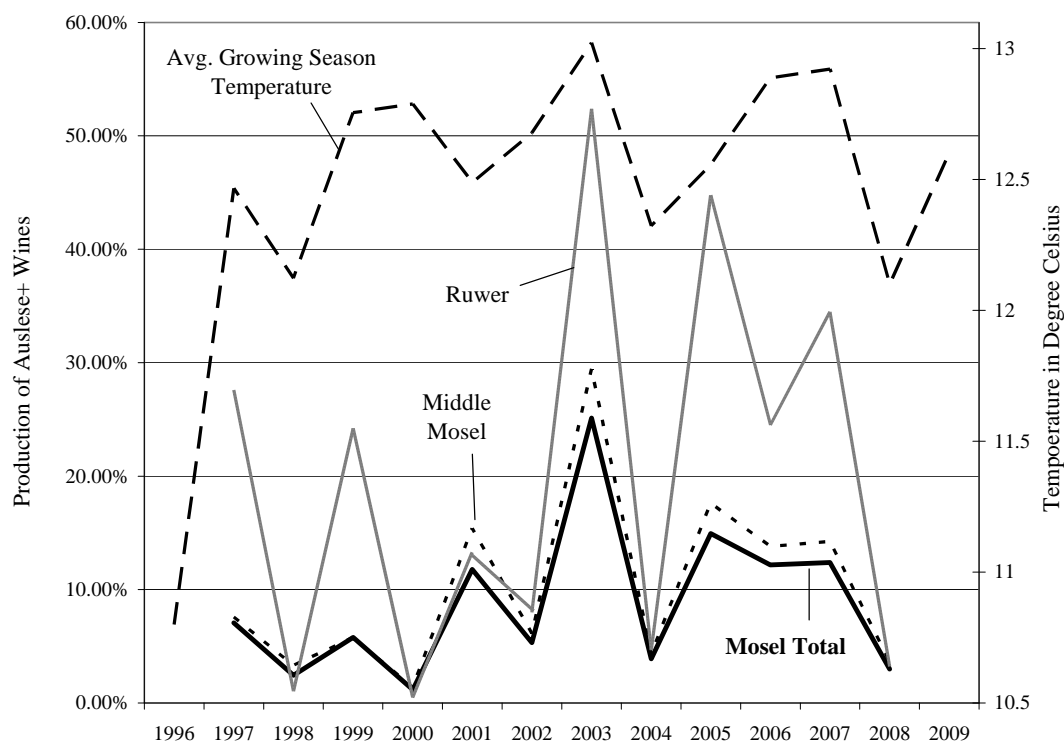
a) February to October, b) December to February, c) April to October d) in real prices. e) Trockenbeerenauslese, f) Beerenauslese g) for three wines in the sample we could not obtain Oechsle measures; we thus only refer to 2395 of the 2398 wines; significance levels of 1% (***), 2% (**), 5% (*); Newey-West robust t-values in parentheses;

Another interesting feature of Figure 1 is the apparent upward trend in temperatures.⁹ At the same time there is also an apparent upward trend in the amount of higher quality wine being produced. This has led many observers to remark on the increased prosperity of the Mosel wine region in recent years. Figure 2 shows the annual

⁹ Using data over the longer period from 1960 to 2006, a regression of average temperature on a trend variable (and a constant term) yields a coefficient of 0.034 at the 0.01% significance level. Thus, since 1960 average growing season temperatures in the Mosel valley have increased by 1.6 Centigrade.

growing season temperatures in the Mosel valley from 1960 to 2009. It is evident that the increase in average growing season temperatures began in the mid 1980s, well before our sample period.¹⁰ It is unclear, of course, whether this is a result of permanent climate change or something more transitory.

Figure 1
Growing Season Temperatures and High End Wine Production
 Percentage production of Auslese+ Wines in Selected Mosel Districts



¹⁰ For longer time series data on weather and wine quality from the year 1700 on see Storchmann (2005).

Figure 2
Average Growing Season Temperatures in the Mosel Valley 1960 – 2009
 in degree centigrade, five-year moving average

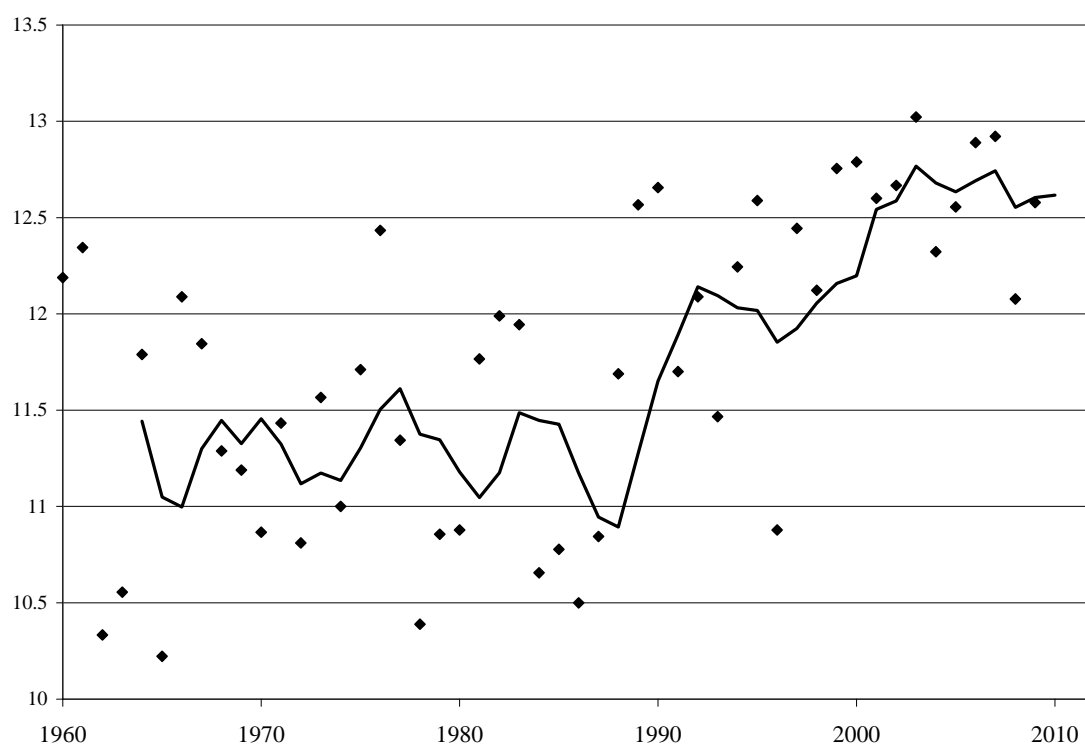


Table 6
Weather and Revenue

	Dependent Variable		
	(1) ln(Revenue based on Retail Prices) ^{d)}	(2) ln(Revenue based on Wholesale Prices) ^{d)}	(3) ln(Revenue based on Auction Prices) ^{d)}
Constant	8.251 (0.34)	18.166 (0.89)	-23.015 (-0.66)
Growing Season Temp ^{a)}	0.373*** (2.82)	0.265** (2.47)	0.633*** (2.94)
Rain Winter ^{b)}	-0.000 (-0.07)	-0.000 (-0.28)	-0.000 (-0.19)
Rain Growing Season ^{c)}	-0.0002*** (-3.40)	-0.0001*** (-2.91)	-0.0002*** (-2.87)
Trend	-0.003 (-0.23)	-0.007 (-0.76)	0.012 (0.69)
R2	0.767	0.793	0.785
F statistic	9.62***	10.04***	7.91***
n	60	48	60

a) February to October, b) December to February, c) April to October d) in real prices (district fixed effects are not reported). significance level of 2% (***), 5% (**), 10% (*); t-values based on year-clustered standard errors in parentheses

Table 6 reports the relation between per hectare revenue and weather. In addition to weather variables we also included a trend variable to control for possible time-dependent effects such as technological progress or changing marketability of Mosel wines as a whole. It is apparent that revenue per hectare significantly increases with warmer weather. However, the extent of this effect is dependent on the underlying price sample of the revenue data.

Table 6
Weather and Revenue

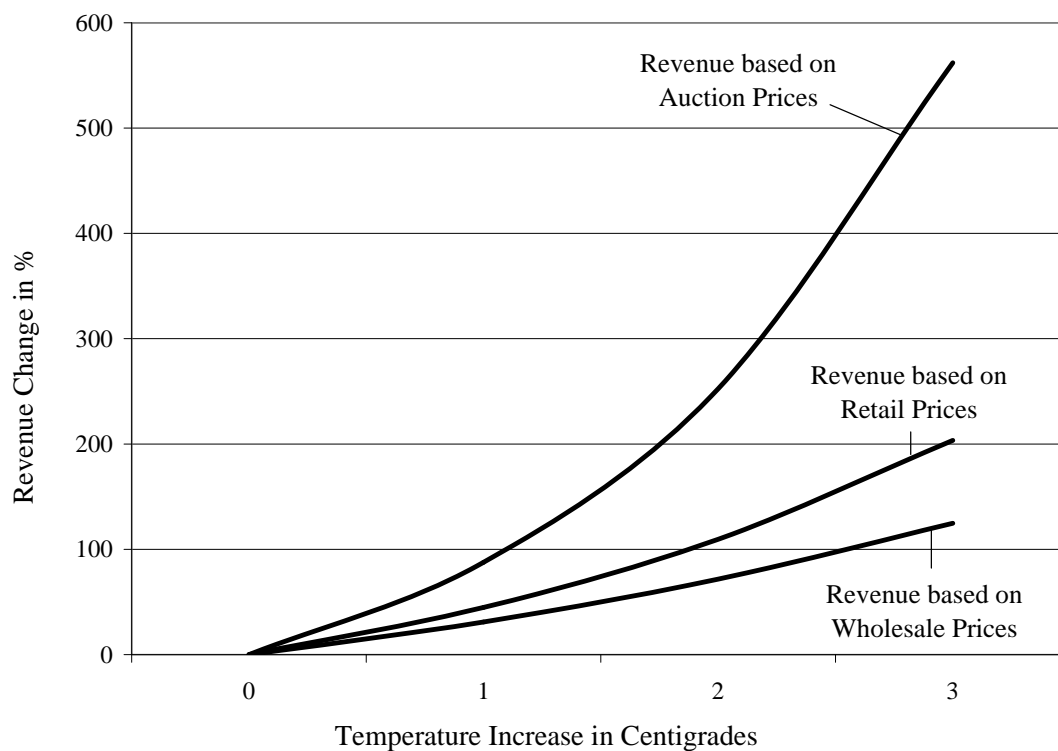
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Constant	8.251 (0.34)	18.166 (0.89)	-23.015 (-0.66)
Growing Season Temp ^{a)}	0.373*** (2.82)	0.265** (2.47)	0.633*** (2.94)
Rain Winter ^{b)}	-0.000 (-0.07)	-0.000 (-0.28)	-0.000 (-0.19)
Rain Growing Season ^{c)}	-0.0002*** (-3.40)	-0.0001*** (-2.91)	-0.0002*** (-2.87)
Trend	-0.003 (-0.23)	-0.007 (-0.76)	0.012 (0.69)
R2	0.767	0.793	0.785
F statistic	9.62***	10.04***	7.91***
n	60	48	60

a) February to October, b) December to February, c) April to October d) in real prices (district fixed effects are not reported). significance level of 2% (***), 5% (**), 10% (*); t-values based on year-clustered standard errors in parentheses

While the auction price-based sample suggests revenue increases of more than 63% per centigrade, the wholesale and retail price-based revenue data suggest revenue increases between 27% and 37% per centigrade. It is apparent that the auction price-based sample measures the impact of temperature changes for high-end wine producers only. The focus of auctions on high-end wines suggests that the auction price-based sample is likely to overestimate the overall impact of temperature on revenue. In contrast, the other two samples, although based on very different price data, lead to similar results that are in a plausible range for the overall wine production in the Mosel valley. In addition, an entirely different model by Ashenfelter and Storchmann (2010) employing a

model of solar radiation also suggests revenue increases of about 30% per temperature increase by one centigrade. The rainfall variables are either insignificant or have unexpected signs. Assuming that cost and temperature changes are not correlated (as shown by Ashenfelter and Storchmann, 2010), these revenue changes will translate directly into changes in profits and land values. Figure 3 displays the model results in graphical form.

Figure 3
Temperature Changes and Percentage Changes in Revenue



IV. Conclusion

In this paper we have computed estimates of the effect of annual time-series weather changes on vineyard profitability and revenue. We provide and compare the results of three models based on different price data, i.e., retail, wholesale and auction prices. All models suggest that the vineyards of the Mosel Valley will increase in value

under a scenario of global warming, and perhaps by a considerable amount. We found that auction prices are likely to misrepresent the actual structure of Mosel wines produced by focusing on the high end of the quality scale. They thus may overestimate the impact of temperature increases. In comparison, retail and wholesale prices lead to almost identical results that also square with the results of Ashenfelter and Storchmann (2010) using a hedonic model of solar radiation.

As is well known, there are likely to be winners and losers from any potential climate change. Wine revenue increases more than proportionally with greater ripeness, so that we estimate a 3°C increase in temperature would more than double the value of this vineyard area, while a moderate 1°C increase would raise revenue by about 30 percent.

There are several limitations of these results. First, our empirical analysis does not take account of general equilibrium effects that might result in a restructuring of land prices. The Mosel Valley is suited primarily for grape growing only, so a change in the relative price of vineyards of different quality induced by climate change could have a dramatic effect on our calculations. Second, our results provide only a small part of an overall appraisal of the role of climate change on agricultural values. There are no doubt places where increased temperatures will decrease the quality of wine grapes because of excessive heat. Only additional research will provide the evidence to evaluate these issues more completely.

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