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The Development of Irrigation in Provence, 1700–1860: The French Revolution and Economic Growth

JEAN-LAURENT ROSENTHAL

Quantitative and qualitative evidence suggest that the returns to irrigation in France were similar during the eighteenth and nineteenth centuries. The Old Regime failed to develop irrigation because of fragmented political authority over rights of eminent domain. Since many groups could hold projects up, transaction costs increased dramatically. Reforms enacted during the French Revolution reduced the costs of securing rights of eminent domain.

Historians and economic historians hotly debate the issue of the French Revolution's contribution to economic growth. Most view the French Revolution either as testimony to the Old Regime's inability to survive in the world created by the Industrial Revolution, or as the unfortunate result of poor political calculations on the part of the nobility or the king's ministers.[1] Hence scholars have focused on the causes of the Revolution. As Alfred Cobban argues, however, the true measure of such an event probably lies in its consequences.[2] Although economic historians have tended to point to technological change as the crucial source of economic growth, more and more attention is being paid to the development of markets and to the relationship between institutional change and economic growth.[3] One important area where it has been argued that institutions held back development in Old Regime France is agriculture. This article attempts to assess the impact of the Revolution of 1789 on a specific agricultural investment—irrigation in southeastern France. I show that both quantitative and qualitative evidence suggest that irrigation was profitable under the Old Regime. To

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[1] See, for example, Donald Sutherland, *France 1789–1815: Revolution and Counterrevolution* (Oxford, 1985); and Michel Vovelle, *La Chute de la monarchie, 1787–1872* (Paris, 1972).

[2] Alfred Cobban, *The Social Interpretation of the French Revolution* (Cambridge, 1968), p. 67.

[3] See Douglass North, *Structure and Change in Economic History* (New York, 1985); see also Philip Hoffman, "Institutions and Agriculture in Old-Regime France," *Politics and Society*, 16 (June-Sept. 1988), pp. 241–64.

explain the lack of growth in irrigation before 1789, I explore legal constraints and argue that divided authority over rights of way was the most important factor responsible for hindering agricultural growth.

The narrowness of the topic—irrigation in Provence—is dictated by the need for precise knowledge of institutions and their historical context. Since law and the distribution of political power varied greatly across regions in Old Regime France, a national approach to institutional problems would miss details that might explain the diversity of regional performance and failure. My conclusions, however, should hold for most of eighteenth-century France, because any investment project that featured externalities would have been plagued by the same problems that plagued irrigation.

IRRIGATION AND PROVENÇAL AGRICULTURE

Considered from a geographic point of view, Provence, one of France's more arid regions, was an area where development of an irrigation network should have had the greatest impact before 1789.[4] Years when rainfall is negligible from June to October are frequent, restricting agricultural production to grains, grapes, and olives on dry fields. The obvious remedy to the arid climate was, and remains, irrigation. Until the twentieth century the main source of irrigation water was the Durance River, a tributary to the Rhône.

Because the water of the Durance is very silty, it acts as a natural fertilizer, which permitted eighteenth-century farmers to avoid the biennial fallow on irrigated plots. The abandonment of the fallow alone indicates how dramatic an impact irrigation could have on total output. Yet the value of output would have probably more than doubled because irrigation also allowed farmers to abandon traditional crops in favor of fodder grasses, peas, beans, and other high-value crops. These more valuable crops require both the warmth of the summer and significant amounts of water. Thus irrigation could lead to substantial per-acre increases in output.

A more accurate measure of the increase in efficiency associated with irrigation involves estimating the rise in total factor productivity, a measure of productivity change that takes into account the fact that more labor and capital were applied to irrigated than to dry land. Using sharecropping contracts to trace changes in the quantity of labor and capital applied to the land, I estimate that total factor productivity per acre

[4] Throughout the article Provence will denote the present-day *départements* of the Vaucluse and the Bouches du Rhône. While these departments represent only lower Provence, the rest of southeastern France, namely, the Côte d'Azur and upper Provence, has a much lower potential for irrigation development.

would have risen at least 30 to 40 percent as a result of irrigation.[5] Thus irrigation would have represented a significant increase in efficiency.

Unlike farmers or landowners, Old Regime royal governments may have been less concerned with increasing production on specific plots of land than with raising regional agricultural output. Using data from the 1870s I compute a conservative estimate of the change in total factor productivity as a result of the development of irrigation after 1789 (see the Appendix for details). Had the canals planned or proposed under the Old Regime, but only realized after 1789, been built in the eighteenth century, the increase in total output in the region would have been more than 7 percent.[6] While an output increase of 7 percent at the regional level may seem small, it would have significantly eased any short-term Malthusian constraints on the population, the very problem that concerned so many government officials.[7] A qualitative survey of the geography and economy of eighteenth-century Provence thus suggests that irrigation should have seen greater development under the Old Regime. The benefits of irrigation were well known long before 1820, when the development of irrigation began in earnest. Indeed, some of the canals of southeastern France dated back to the Middle Ages.[8] Many irrigation projects were proposed between 1700 and 1789, so we must look to something other than ignorance to explain why irrigation grew so slowly before 1789.

PROFITABILITY

Improvements in technology, credit markets, or relative price changes are all potential causes for the sudden development of irrigation canals after 1820. Using data from projects built between 1760 and 1860, we shall see that neither profits nor techniques, nor even credit was the determining factor in the timing of irrigation development.

Let us first assume that there was little technical change and that credit was easily available and present the data collected to examine the issue of profits.[9] Too few canals were built between 1700 and 1860 to measure directly the profitability of irrigation projects. Moreover no

[5] Abandoning the fallow leads, over two years, to twice the output on the same piece of land but at the cost of more labor and capital. Farmers probably invested some labor and capital on the fallow, so irrigation would not double labor and capital inputs. Because I want to compute a lower bound for total factor productivity growth, I assume that labor and capital inputs double. The assumption that nonland inputs double is consistent with estimated labor and capital inputs from rental contracts.

[6] Provence was a net importer of grain throughout the eighteenth century. Thus the increased output could have been either consumed locally or used to purchase more food.

[7] Not surprisingly, Old Regime government officials promoted irrigation, but royal government protection proved insufficient to overcome institutional obstacles.

[8] The canals of Saint-Julien in Cavaillon and l'Hôpital in Avignon were built between 1200 and 1350.

[9] I defend these assumptions in the section titled "Technology and Credit."

irrigation projects were realized until 1765 in Provence. It is possible, however, to estimate the level of profits that projects would have earned had they been started earlier than 1765. Estimating rates of return requires three kinds of data: price series for the inputs and outputs of canal construction; factor shares for each canal; and an interest rate series (because the costs and benefits are spread over time).

Unfortunately, canal accounts are not very detailed. Except in the case of skilled and unskilled labor, it is difficult to get factor shares for such things as quarried stone, lime, wood, and other material inputs. However, since nonlabor inputs were mostly used on bridges and in a few buildings, land and labor comprised nearly all the costs of canal construction. The measure of costs for a canal includes building costs and maintenance costs. For the jth construction year expenditures are divided between man-days spent digging using unskilled labor (d_u^j), man-days of construction, which requires skilled labor (d_s^j), and the amount of land consumed by the canal (n). Man-days of labor and acres of land are bought at market prices w_u^t, w_s^t, and p_i^t (all land bought for the canal is assumed irrigated, which biases the rates of return downward). The present value of future maintenance costs is the yearly maintenance cost (m) divided by the interest rate r^t.

The social return to building a canal is taken to be the increase in the price of land when it becomes irrigated ($p_i^t - p_d^t$). Since land is the only input in fixed supply, in the long run the net increase in output from irrigation should accrue to the owner of the land. Thus if N acres of land become irrigated, the social return will be N times ($p_i^t - p_d^t$). Given these assumptions one can compute the hypothetical benefit-cost ratio, R^t, had the project started in year t and taken T years to complete:[10]

$$R^t = \frac{N(p_i^t - p_d^t)/(1 + r^t)^T}{\sum_{j=0}^{T} (d_u^j w_u^t + d_s^j w_s^t + np_i^t)/(1 + r^t)^j + \dfrac{m}{r^t(1 + r^t)^T}}$$

To estimate hypothetical profits, I was able to construct two different wage series, using data from Avignon, a large town in the middle of the area.[11] The data consist of wage bills for unfed labor from the account

[10] The hypothetical internal rate of return is simply the r^{t*} that sets R^t equal to 1.

[11] For any year wages are nearly identical across sources in the area. Avignon, the major city, has the most abundant sources, and the ones which were used to construct the series. The noticeable intraregional pattern was that unskilled labor was somewhat cheaper in nearby villages but skilled labor was more expensive there than in Avignon. There was considerable seasonal fluctuation in wages, partially due to variation in the working day. For further detail, see the Appendix.

books of religious and municipal organizations.[12] Religious institutions owned medieval canals and they hired labor by the day for maintenance work. Thus the wage data come from the very professions involved in canal construction and maintenance. These data have been sorted into two series: skilled and unskilled workers (see Table 4). The first, unskilled labor, was constructed from the wages of laborers, road gangs, and levee maintenance workers. The second was constructed from skilled workers' wages (masons, miners, carpenters, gang bosses, and so on).[13]

The data for the land price series are taken from a sample of land-sale and land-lease contracts negotiated between 1700 and 1855 that were found among the archives of *notaires* in Cavaillon, the town with the largest amount of irrigated land in southeastern France both in the eighteenth and in the nineteenth century.[14] The choice of Cavaillon allows us to ignore any local market effects on the price of improved land. If anything, the fact that Cavaillon had more irrigated land than other areas should bias the price of irrigated land downward and thus underestimate potential canal revenues.[15]

Calculating hypothetical profits also requires data on the costs and revenues of canals built between 1700 and 1860. Data are available for two eighteenth-century projects, Cabedan-Neuf and Crillon, and for two projects proposed in the eighteenth century but not realized until the nineteenth, Plan-Oriental and Carpentras. While there are insufficient data to estimate the profits of other projects, my sample of canals is representative of most canals built between 1700 and 1860, in terms of size, location, and timing. The canal of Carpentras is as large as any in Provence and the smaller ones of Cabedan-Neuf, Crillon, and Plan-

[12] Most of the workers who received food were paid not on a per-diem basis, but on a monthly or yearly basis. Not knowing how many days of work corresponded to a year's wages, I did not use wage bills of workers who received food as part of their compensation.

[13] The data also reflect some of the extraordinary levels of inflation associated with the French Revolution, unlike most series previously published. One excellent source for wage data is René Baehrel, *Une Croissance: La Basse Provence rurale (1650–1789)* (Paris, 1962). Unfortunately Baehrel's data stop in 1789. The sources used for wages came from the *Archives Départementales* in Avignon. The sources include the accounts books of the city of Avignon (AC Avignon, CC 550 to CC 805, *pièces à l'appui des Comptes*), religious institutions (AD Vaucluse, H Bompas 182–185; H Cordeliers Avignon, 62–64), and the hospital of Avignon (AD Vaucluse, H sup. Hôpital Ste Marthe E 103, M 6–18).

[14] Cavaillon is a local market town located 17 miles to the east of Avignon, 30 miles northwest of Aix, on the banks of the Durance River.

[15] In Old Regime France transportation costs were high. If only a small portion of a given area was irrigated, such land would fetch a very high price. When the irrigation network was completed the price would fall dramatically; thus we want to use a price for irrigated land that is close to the price irrigated land would have fetched after the network was completed and a price for dry land that is the price of irrigable dry land. By 1700, 15 percent of the area of Cavaillon was irrigated. The large area irrigated suggests that most irrigation-specific goods would have commanded only a competitive price. Moreover, most of Cavaillon's nonirrigated land under cultivation was irrigable, so we are in fact measuring the price difference between irrigable and irrigated land with reasonable confidence.

Oriental are similar in size to most other projects.[16] Table 1 displays in condensed form all the project-specific data used in the construction of hypothetical profit streams.

The only other data necessary are interest rates. These are taken for the eighteenth century from *rentes* data collected in Provence that have been sorted into decadal averages, and in the nineteenth century from French government bond data.[17]

I estimated both benefit-cost ratios and internal rates of return.[18] All projects were profitable during nearly the entire period under study. But the projects were more profitable before 1750, when they were not carried out, than after 1820, when they were. Although some projects are always more profitable than others, changes in profit rates are similar for all projects. In addition, the profitability of an irrigation canal does not seem to depend on the scale of the project. Profits for any project vary significantly from one estimate to the next, but the benefit-cost ratios are less than 1.2 in fewer than 20 percent of the years. The estimates suggest that any uncertainty about the profits of a canal concerned their magnitude rather than their existence. The dispersion of rates of return and benefit-cost ratios is largely due to variations in the increase in the value of land as a result of irrigation (75 percent of the variance of the benefit-cost ratios is explained by a regression of the ratio on land prices). Because the hypothetical profits of Old Regime projects are similar to the hypothetical profits realized by projects built after 1820, it is unlikely that changes in technology played a major role in irrigation development. Had there been a lot of technological change, later projects should have been much more profitable.

As Table 2 suggests, the highest profits came in the early eighteenth century between 1700 and 1730. During the years 1735 to 1755 projects were less profitable—though not unprofitable—than at any other time except for the Revolutionary period. A number of projects built after

[16] Cabedan-Neuf irrigated 600 hectares in and around Cavaillon and was built from 1764 to 1766; Crillon irrigated 1,000 hectares around Avignon and was completed in 1777. Plan-Oriental, another canal in Cavaillon, watered 800 hectares to the north of Cavaillon; it was built in 1823. Carpentras was very large; built in the 1850s, it irrigated more than 4,500 hectares.

[17] The interest rate data for the eighteenth century comes from J.-L. Rosenthal, "Credit Markets in Southeastern France, 1650–1788" (UCLA Dept. of Economics Working Paper No. 589). For the nineteenth century I have relied on Stanley Homer, *A History of Interest Rates* (New Brunswick, 1977), pp. 156–57, 172, 195–96, 222–23. I preferred to ignore the interest data in David Weir and François Velde, "The Financial Market and Government Debt in France, 1750–1793" (Paper presented at the Second International Cliometrics meeting, Santander, 1989). The data they present come from government interest rates that are significantly affected by the government probability of default. As a consistency check I did estimate benefit-cost ratios using these data with results similar to those from using the *rentes* data. In fact, none of the results depend strongly on the choice of an interest rate, provided it is less than 8 percent. An interest rate of 8 percent is higher than any paid in the eighteenth century by the French government (except in 1770) or by private borrowers.

[18] The data and results are presented in detail in the Appendix.

TABLE 1
CANAL COSTS

Canal	Date of Completion	Land Irrigated (in hectares[a])	Total Building Costs (in francs)	Capitalized Maintenance Costs (in francs)
Cabedan-Neuf I	1767	500	822,300[c]	97,200
Cabedan-Neuf II[b]	1767	270	172,490	97,200
Crillon	1779	1,000	400,000	400,000
Plan-Oriental	1821	590	138,595	100,000
Carpentras	1857	5,000	5,297,011	100,000

Canal	Years Under Construction	Skilled Labor (in man-days per year)	Unskilled Labor (in man-days per year)	Land Requirements (in hectares)
Cabedan-Neuf I	2	88,815	73,053	27.0
Cabedan-Neuf II	2	21,410	19,824	27.0
Crillon	3	35,088	41,190	49.5
Plan-Oriental	2	63,561	46,631	9.7
Carpentras[d]	6			
First 3 Years		61,341	224,242	96.7
Last 3 Years		221,852	112,403	73.3

[a] One hectare equals 2.4 acres.

[b] Cabedan-Neuf I and Cabedan-Neuf II are the same canal, but the various sources on construction accounts could not be reconciled. Not knowing which one was more accurate I present results based on both sets of sources.

[c] All costs are given for the year in which they were incurred. There was no need to deflate them because they are converted into quantities of labor.

[d] Carpentras was a very large canal. For the first three years work focused on the main canal. Only in the next three years were branches built. See René Caillet, *Le Canal de Carpentras* (Carpentras, 1925), vol. 1, pp. 69–70.

Sources: For the first estimate of the costs of Cabedan-Neuf: Jean-Auguste Barral, *Les Irrigations dans le Vaucluse* (Paris, 1876), pp. 539–44. For the second estimate of the costs of Cabedan-Neuf: *Syndicat du Canal de Cabedan-Neuf, Archives et Documents 1230–1883* (Cavaillon, 1883), pp. 45–52. For the canal of Crillon: A. Reboulet, "Le Canal de Crillon," in *Mémoires de l'Académie de Vaucluse* (33, 1914), pp. 37–40; and Barral, *Les Irrigations dans le Vaucluse*, pp. 326–27. For Plan-Oriental: André Martel, "Les Origines du Canal de Plan-Oriental," in *Actes du Congres des Societés Savantes* (Avignon, 1955), pp. 394–95; and Barral, *Les Irrigations dans le Vaucluse*, pp. 545–47. For Carpentras: René Caillet, *Le Canal de Carpentras* (Carpentras, 1925), vol. 2, pp. 199–201; and Barral, *Les Irrigations dans le Vaucluse*, pp. 325–26.

1760 were proposed during this intermediate period, suggesting that investors, at least, found it profitable to attempt irrigation development. The last decades of the Old Regime between 1760 and 1785 show high internal rates of return and high benefit-cost ratios. The rates of the late eighteenth century, were in fact higher on average than those of the nineteenth century when most of the development actually took place. After 1785 the rates of return were highly erratic until 1820, no doubt because of the uncertainties provoked by the Revolution.

The high levels of estimated profits through most of the Old Regime, and in particular during the years from 1700 to 1730, suggest that changes in relative prices were not responsible for the late development of irrigation in southeastern France. During most of the eighteenth

TABLE 2
AVERAGE HYPOTHETICAL INTERNAL RATES OF RETURN
(in percent per year)

Canal	Periods				
	1700–1730	1735–1755	1760–1785	1790–1820	1820–1855
Cabedan-Neuf I (1767)	113.0	32.5	77.8	11.0	63.3
Cabedan-Neuf II (1767)	60.0	2.1	35.3	−16.0	24.2
Crillon (1779)	91.8	33.8	68.6	10.7	57.8
Plan-Oriental (1821)	126.9	49.9	104.0	25.3	78.9
Carpentras (1857)	32.0	13.4	30.0	−1.4	25.0
Interest Rate	5.0	5.1	5.0	7.5	4.3

Sources: Table 6.

century rates of return were in fact higher than they were in the nineteenth century. Yet irrigation development was much more limited from 1700 to 1789 than it was from 1820 to 1860. Indeed, despite the fact that hypothetical rates of return before 1760 were well above the interest rate, no canal was built before that date. Thus some sort of a market failure in the supply of irrigation must have been at work in the eighteenth century.

TECHNOLOGY AND CREDIT

Given the high levels of hypothetical profits, it is important to examine the validity of assumptions made about technology and credit availability. The design of French transportation canals was very sophisticated; these canals involved locks, dams, bridges, and complex water management.[19] The technology of transportation canals was also greatly improved between 1700 and 1855. By contrast, the technology of irrigation seems to have remained the same from the Middle Ages to the late nineteenth century. The methods used between 1700 and 1860 resembled those used in the thirteenth century in building the canals of Saint-Julien and l'Hôpital, or in the sixteenth century in building the canal of Craponne.[20] From 1200 to 1870 all new irrigation canals were unlined dirt ditches, where water flowed by gravity alone. Stone masonry was used only for bridges. The only dams in use, flimsy dirt levees that captured the water from the Durance River, had to be rebuilt after every large flood. They diverted part of the river's flow but made no attempt to retain water in a reservoir.

Agricultural development simply could not support the innovative,

[19] A valuable source on eighteenth-century canal technology is Delalande, *Des Canaux de navigation* (Paris, 1777). See also André Maistre, *Le Canal des deux mers: Canal royal du Languedoc, 1666–1810* (Toulouse, 1968), chap. 3.

[20] Jean Rigaud, *Le Canal de Craponne, Etude historique et juridique relative aux concessions complexes des arrosages communaux d'Istre et Grans* (Aix-en-Provence, 1934); Roger Caillet, *Le Canal de Carpentras* (Carpentras, 1925), chaps. 2, 3.

but very expensive, technologies used for urban water supply and transportation. In contrast to the low levels of technological sophistication utilized in agricultural projects stands a set of urban projects that overlaps both geographically and temporally with those under study. One project, the canal of Marseille (1840 to 1848), a joint urban and rural water-supply project, offers a good example of the technologies available in the nineteenth century yet not used in agriculture. The canal of Marseille featured a large dam and a permanent reservoir, many bridges, and it ran underground for 25 percent of its length. The project was financed by the city of Marseille, which attempted to sell excess water to farmers. The city also wanted farmers to pay a share of the building costs equivalent to their share of the water. This led to a price for water 15 times the cost of water on other agricultural projects. As a result, the scheme to retail excess water to farmers failed.[21]

Despite the available technology the methods used to build irrigation canals did not change. Yet it is possible that experience gained from past canal construction led to smaller engineering errors. The resulting reduction in risk would have increased the viability of projects by lowering the risk premiums demanded by investors. Yet technological risks—the risks associated with the construction phase of the project—seem to have been very limited. Even in the eighteenth century the relationship between technology and cost was well established. Engineering costs could be predicted with a good deal of confidence because of the experience gained from transportation canals, which were much more complex and thus riskier. Irrigation projects were by contrast very simple, even when there were unanticipated delays or higher-than-expected costs.[22] It thus appears that between 1700 and 1860 change in the methods of irrigation canal construction was limited, and technological risk did not threaten irrigation projects or constrain the supply of irrigation.

Because the construction of irrigation canals involved considerable cash outlays, the assumption that credit was easily available is crucial for my argument. While Old Regime France lacked a well-developed, centralized credit market, the limited development of credit markets did not block the expansion of the irrigated area of Provence.[23] In defense

[21] Paul Masson, *Encyclopédie des Bouches du Rhône* (Paris, 1929–1930), vol. 7, pp. 162–67. This canal ran nearly 100 kilometers through a very rugged part of Provence to deliver water to Marseille.

[22] The canal of Boisgelin, the most ambitious canal realized prior to the Revolution, shows that risk was small. The engineer, Brun, had warned of the very large costs associated with the tunnel. Yet he did not doubt that the tunnel could be built. BM Méjanes, Ms. 840(853). My section titled "Institutional Failure: Eminent Domain and Rent-seeking" will discuss how institutional factors raised costs on this canal.

[23] Pierre Goubert, *L'Ancien Régime* (Paris, 1973), vol. 2, chap. 7, offers an introduction to Old Regime finance. See also Guy Chaussinant-Nogaret, *Les Financiers du Languedoc au XVIII^eme siècle* (Paris, 1976).

of this position one can marshal four different kinds of evidence. First, the credit demands of most irrigation canals were tiny relative to the credit demands of Provençal villages that borrowed extensively during the Old Regime. Second, credit markets based on mortgages, which were very active in rural France, could have provided significant sources of capital for irrigation promoters, who were often wealthy landowners.[24] Third, Jewish agents were directly involved in making loans to at least one promoter in the 1780s. These loans did not have the collateral of land and the promoter paid an interest rate double that of the mortgage rate—8 to 10 percent as compared to 5 percent. Fourth, the high nobility was also able to finance projects directly in the case of many of the smaller projects, perhaps putting its vast wealth at the disposal of canal promoters because irrigation canals did not carry the stigma attached to many other forms of investment.[25] Therefore, it seems there were sufficient sources of capital (though not necessarily through organized markets) to carry out irrigation projects.

Finally, the apparent market failure in irrigation cannot be ascribed to a lack of acumen on the part of Old Regime investors. In fact the magnitude of entrepreneurial activity is striking when it is contrasted with the failures endured by canal promoters before 1789. Every canal built after the Revolution can be traced back to a serious promoter under the Old Regime who had expended considerable resources attempting to secure all the authorizations needed to build the canal. These promoters failed overwhelmingly, if we measure success by the ability to build a canal and earn a profit. The failure rate remains very high even if we demand only that a canal be built. Indeed, the pre-Revolutionary expansion of the irrigated area represents only 16 percent of what was actually planned before 1789 and built before 1860. Simple economic arguments do not seem to explain the failure of irrigation development under the Old Regime or its success after the Revolution. Instead, it seems that the peculiar fragmentation of power that characterized the Old Regime constrained Provençal canal promoters.

[24] The canal of the Midi was primarily financed by the estates of Languedoc through loans. See Robert Forster, *The Nobility of Toulouse in the Eighteenth Century: A Social and Economic Study* (Baltimore, 1960), pp. 66–74; William Beik, *Absolutism and Society in Seventeenth-Century France: State Power and Provincial Aristocracy in Languedoc* (New York, 1985), pp. 292–97; and Maistre, *Le Canal des Deux Mers*, chap. 4.

[25] See Paul Masson, "Le Canal de Provence," in *Revue historique de Provence* (Aix-en-Provence, 1901), pp. 423–25; Hubert Elie, "La Spéculation sous la Régence: l'Affaire du Canal d'Avignon à la Mer," *Provence Historique*, 3 (1953), pp. 112–13; and A. Reboulet, "Construction du Canal de Crillon," *Mémoires de l'Académie de Vaucluse*, 33 (1914), pp. 46–47. In the case of the canal of Crillon, 25 percent of the construction costs was advanced by Jews and another 25 percent by nobles and bourgeois. Landowners were the largest source of credit in France because they could borrow money through mortgages. Had promoters been able to interest more than a small number of landowners, the credit problem would never have existed.

INSTITUTIONAL FAILURE: EMINENT DOMAIN AND RENT-SEEKING

While the failure of the supply of irrigation had multiple causes, the most important, I would argue, lay in the division of authority over rights of eminent domain.[26] This problem was well understood before 1789, yet resolution was elusive because eminent domain authority was embedded in the Old Regime structure of privileges.

The woes of a sixteenth-century canal builder illustrate the costs of divided authority. In 1554 Adam de Craponne, a Provençal nobleman and engineer, received a royal grant to draw water from the Durance. In order to secure eminent domain rights for his canal, Craponne had his grant acknowledged by the local assembly—the Estates. Yet some Provençal communities (called *Terres Adjacentes*) did not come under the jurisdiction of the Estates as far as eminent domain was concerned. These villages delayed the project until Craponne gave farmers there unlimited, free access to the canal's water.[27]

Despite these outlandish concessions Craponne completed his canal in 1559 and sold a number of irrigation rights. In dry years, however, *Terres-Adjacentes* villages used up most of the canal's capacity, and with no water to deliver, Craponne had to renege on his other contracts. The resulting suits led Craponne to an early bankruptcy and discouraged other investors from pursuing irrigation projects. From the standpoint of *Terres-Adjacentes* villages, the whole affair was a free ride. Although Craponne's bankruptcy saddled them with part of the maintenance costs, they now received irrigation water without the burden of any construction costs. Divided authority over eminent domain could indeed create severe problems for canal developers.

The structure of authority Craponne encountered in the sixteenth century was a legacy of medieval state building, and it remained in place until the Revolution of 1789. After the division of Provence between the Pope and the counts of Provence in the twelfth century, the Pope's share became known as the *Comtat* Venaissin (hereafter the *Comtat*). The *Comtat* corresponds to the present-day *département* of the Vaucluse. The counts of Provence retained control of the *Comté* of Provence and the *Terres Adjacentes*. The western half of the *Comté* of Provence (hereafter the *Comté*) and the *Terres Adjacentes* make up

[26] Other causes of failure were the costs associated with securing water rights and the severe revenue problems related to the fact that most of the costs of the network were sunk when the builder bargained with landowners to sell them water rights. Although these other causes were important, they were due to the same division of authority that encouraged rent-seeking over rights of eminent domain. Focusing solely on rights of way simplifies the argument.

[27] On the canal of Craponne see J.-B. Bertin and P. Autier, *Adam de Craponne* (Paris, 1904); Rigaud, *Le Canal de Craponne*; Jean de Villeneuve, *Encyclopédie des Bouches du Rhône* (Marseille, 1825–1829), vol. 3, pp. 698–714; and Masson, *Encyclopédie*, vol. 7, p. 148.

what is now the *département* of the Bouches du Rhône.[28] In 1481 the king of France inherited the *Comté* and the *Terres Adjacentes*.

The geographic divisions outlined above corresponded to organizational divisions that seem to have determined the transaction costs of irrigation. Prior to the Revolution, two organizations alone should have decided the fate of irrigation projects in the *Comtat*, although, as this article will make clear, their authority was far more limited. These organizations were the Estates of the *Comtat*, a representative assembly in charge of taxation, and the Apostolic Chamber, the *Comtat*'s final court of appeals. The approval of the Estates was necessary to secure financial or legal support for irrigation projects, but the Pope and his local representative (the vice legate) had veto power over decisions by the Estates, a veto power they regularly exercised. Similarly, the Apostolic Chamber was a court of last resort and should have enforced all contracts relating to irrigation. In fact, appeals were possible either to the Chamber itself or in some rare cases to papal courts in Rome.[29]

The *Comté* of Provence had organizations similar to those of the *Comtat*. As a French *Pays d'Etat* it had, like the *Comtat*, a fiscal and legislative body—the *Assemblée du Pays*. Like the Estates of the *Comtat*, the *Assemblée du Pays* could provide a locus of bargaining for institutional change. As far as the judicial system in the *Comté* was concerned, the final court of appeals was the *Parlement* of Aix.[30]

The final area under study, the *Terres Adjacentes*, was classified as a *Pays d'Election*. These communities were directly under the authority of the king and had no Estate. In these villages the division of judicial authority among the king, the villages, and the *Parlement* of Aix was very ambiguous. Most importantly for this study, individual villages rather than a central authority seem to have controlled eminent domain rights. In the Middle Ages the *Terres Adjacentes* had been autonomous and had in fact decided issues of eminent domain alone. Under the Old Regime the extent of local autonomy was uncertain and subject to erosion by the Crown. Yet the *Terres-Adjacentes* villages were well organized and could credibly threaten to sue anyone who did not secure rights of eminent domain from them.

One might assume that the political border that ran between *Comtat* and *Comté* was the root cause of the institutional problems, but in fact

[28] The *Terres Adjacentes* were a set of administratively independent communities that included Marseille, Arles, and a number of villages on the border between the *Comté* and the *Comtat*. These communities had never been directly incorporated into Provence. In fact, until they became part of France, the *Terres Adjacentes* recognized only the direct authority of the Count of Provence. The best reference detailing the political divisions of Provence is Edouard Baratier, *Histoire de la Provence* (Toulouse, 1969). For more detail, see Masson, *Encyclopédie*, vol. 4; and Villeneuve, *Encyclopédie*, vol. 3.

[29] Elie, "La Spéculation sous la Régence," pp. 112–13; and Reboulet, "Construction du Canal de Crillon," pp. 37–50.

[30] Masson, *Encyclopédie*, vol. 7.

the two territories were divided by the Durance River. Thus most canals were either in the *Comtat* or in the French part of Provence, even though nearly all drew water from the Durance. So most *Comtat* affairs were strictly *Comtat* affairs and the same was true in the French part of Provence. Moreover, the problems of eminent domain were sufficiently important within each political division that we can ignore the effect of the *Comtat*'s independence from France. Let us, for example, consider rights of eminent domain in the *Comté*. Since any canal on the southern side of the river would irrigate land mostly in the *Comté*, the king, the Estates, and the *Parlement* would all be involved in granting rights of way; however, the need to cross the *Terres Adjacentes* added a further cost. In the *Comté*, the best sites from which to draw water from the Durance were in, or led into, the *Terres Adjacentes*. Thus villages that ruled over eminent domain in the *Terres Adjacentes* could block or delay projects.[31]

The hypothesis that divided authority over rights of way made it very difficult to build irrigation canals is difficult to test. Nonetheless it is possible to examine the history of five Old Regime canals to see whether institutions significantly raised the costs of irrigation. One relationship emerges from these histories: the more institutional boundaries canals crossed, the more difficult they were to build.

Of the four small canals completed under the Old Regime, three were in the *Comtat* and the fourth in the *Comté*. Each of the four projects distributed water to, at most, a few communities. They did not cross any important political boundaries, yet even among the four projects delays and transaction costs rose with size.

The two smallest canals, Janson and Cambis, were each only a few kilometers long and faced only minor transaction costs. Each was entirely financed by the principal landowner—the Marquis of Janson and the Duke of Cambis—who wanted to irrigate his very large estate. The marquis and the duke both maintained strong political ties to the French royal court, and they successfully lobbied for water grants. Their large estates eliminated the free-rider problem and allowed each nobleman to internalize most of the benefits of his irrigation canal. In his grant application the Marquis of Janson argued that the benefits to his estates would more than suffice to cover the construction costs.[32] He did allow the neighboring community to use the canal for irrigation purposes, no doubt to facilitate his use of rights of eminent domain. But there is no evidence to show that he or Cambis failed to make a profit from the canals, even though the villages did not contribute to construction costs. In any case, unlike the other examples, these two small

[31] Bertin and Autier, *Adam de Craponne*, p. 113.
[32] AN H[1] 1515 (March 1780).

canals were completed swiftly and experienced little in the way of transaction costs.

The third project actually completed was the canal of Cabedan-Neuf, built in the *Comtat* around 1765. Although it affected only three communities—Cavaillon, Les Taillades, and Merindol—it was large enough to create problems with eminent domain. The canal was built by an association of landowners under the tutelage of the city of Cavaillon. Because most of the land irrigated by the canal was either in the territory of Cavaillon or in that of Les Taillades, costs of the canal were apportioned between the two villages according to the area irrigated. The third village involved, Merindol, enjoyed a generous free ride. Much of the canal passed through Merindol, which, unlike Cavaillon, lay in the *Comté* not the *Comtat* and thus was not subject to the powers of eminent domain of *Comtat* authorities. Not surprisingly Merindol sued Cavaillon over rights of eminent domain. The issue was settled out of court: Merindol received water from the canal, but it did not contribute anything to the project.

Except for the redistributive implications, the free-riding by Merindol was relatively unimportant: it did not stop the project. Litigation was avoided because Cavaillon alone could have paid for the entire canal and still benefited from the project.[33] Yet the history of Cabedan-Neuf demonstrates that the involvement of a mere three communities was enough to drive institutional costs higher than when only one community was involved. These institutional costs were associated with scale because of the extreme division of authority in the region.[34]

The fourth canal, the canal of Crillon, delivered irrigation water to Avignon and surrounding communities. It was built by the Duke of Crillon, descendant of an old line of *Comtat* noblemen who had led the French king's armies. Using his favor at court, Crillon secured a grant to draw water from the Durance. He then had the grant registered in the *Parlement* of Aix. Next he secured rights of way from the city of Avignon that were recognized by the Estates of the *Comtat* and the vice legate. The canal, however, ran through several communities and challenged the water monopolies of a number of seigniors and monasteries, all of whom held the project up for ransom by attacking it in court. The most important suit was brought by the Duke of Gadagne, Lord of Vedene, one of the communities traversed by the canal. Gadagne contested Crillon's right both to cross into Vedene and to cross

[33] *Syndicat du Canal de Cabedan-Neuf, Archives et Documents 1230–1883* (Cavaillon, 1883), pp. 48–69. Cavaillon chose to bargain with Merindol directly rather than with the *Assemblée* for a right of eminent domain. Presumably both Merindol and the *Assemblée* were seeking rents and Merindol proved cheaper to pay off.

[34] Across the Durance, in the *Comté*, the town of Châteaurenard also attempted to build a canal in the 1780s. Châteaurenard was also forced to negotiate over rights of way and water rights with the nearby town of Noves and its seigniors. See Jean-Auguste Barral, *Les Irrigations dans les Bouches du Rhône* (Paris, 1875), vol. 1, pp. 370–71.

Gadagne's irrigation canal. The suit was temporarily settled out of court in 1777, and in the settlement Gadagne granted rights of way in return for water rights. The settlement was not fully executed by either party and the case was still being litigated after the French Revolution.[35]

The canal of Crillon demonstrates the need for precise geographical and historical detail. Gadagne could litigate against Crillon only because the canal's rights of eminent domain had been granted first by the city of Avignon and only then approved by the Estates. Avignon and the Estates had a complex relationship because the city was in fact a *Terre Adjacente* of the *Comtat*, having been bought by the Pope from the counts of Provence in 1348. As a result the authority of the Estates over Avignon was unclear. Although the Estates and other *Comtat* organizations had approved the canal, they had not specifically granted rights of way in the *Comtat*. Thus the validity of the Duke of Crillon's rights of eminent domain was subject to dispute and formed an open avenue for anyone to attack the project.

The history of the canal of Boisgelin, my fifth example, shows the costs of fragmented authority in a large-scale project, built in the *Comté* under the financial authority of the *Assemblée du Pays* after a number of other attempts had failed. The proposed canal had two possible routes: one ran through the *Comté* alone; the other crossed the *Terres Adjacentes*. While the latter would have been cheaper, it involved bargaining with the *Terres Adjacentes* for rights of eminent domain. Rather than bargain with each village in the *Terres Adjacentes*, the *Assemblée du Pays* avoided the issue but paid a very high price.[36] The *Assemblée* opted for the all-*Comté* route—much more expensive from an engineering standpoint because it involved tunneling through about one kilometer of solid rock near the village of Orgon. The cost of tunneling totaled nearly 400,000 livres and absorbed half the yearly budget of the canal for eight years.

Yet piercing the rock of Orgon allowed the promoters to avoid the *Terres-Adjacentes* villages of Sénas and Salon, where the cheaper route lay. Once the tunnel was built, the *Assemblée* had the ability to exclude the *Terres Adjacentes* from the benefits of the new canal if they did not contribute to its cost. Not surprisingly, the *Terres-Adjacentes* communities did purchase a significant amount of water from the canal just before the French Revolution, and a branch canal through Sénas and Salon was built.

Unlike all other irrigation projects, which involved little more than the digging of ditches, the canal of Boisgelin had to resort to an extraordinarily costly technology, a technology imposed by institutional

[35] BM Cecano, Ms. 2549. Appeals were heard in the Apostolic Chamber and then in Rome throughout the 1780s. Again the settlement gave free water to Gadagne.

[36] See Villeneuve, *Encyclopédie*, vol. 3, pp. 714–21.

constraints. Once again the division of authority led to much higher transaction or institutional costs than if only a small canal had been built. In this case these institutional costs took the indirect form of digging a tunnel at Orgon rather than bargaining or litigation.

Thus the histories of a few projects make it clear that the institutional environment blocked irrigation by raising the cost of canal building. The obstacles had their origins in the long-term development of institutions in southeastern France. One either had to pay off obstructionist villages, as Craponne did, or bear much higher construction costs, as did the promoters of the canal through Orgon.[37] The presence of organizations like the Estates and the *Parlement* did allow for some institutional change. It was, after all, possible to build the canal of Boisgelin. But the sort of institutional change that would have substantially reduced costs lay outside the authority of these organizations. In fact, not even the king, the *Parlement*, or the *Assemblée* could reform the *Terres Adjacentes*. Their peculiar status indeed constituted a *privilège*, something only the Revolution would change.[38]

Irrigation was an easy prey for rent-seeking villages because it involved both economies of scale and significant geographical specificity. Canals were networks; hence the costs involved in building the main canals did not rise as quickly as the irrigated area increased. Moreover, because canals relied on gravity to move water, each area usually had a single most economical drawing site from the river. As a result villages close to the Durance could credibly threaten irrigation projects with much higher costs or insurmountable engineering problems if they refused to grant rights of eminent domain. Most often villages were in a position of such strength that promoters could only give in or give up.

The phenomenon of villages holding irrigation projects up for ransom was not due to the specific form of village organization in eighteenth-century Provence. In fact, as the well-known examples of the sale of judicial offices and the monopolies of craft guilds suggest, rent-seeking was commonplace under the Old Regime.[39] Ironically, in the case of irrigation the greatest rent-seeker of them all, the Crown, was generally allied with canal promoters against local powers that were holding up the projects. Yet the Crown proved powerless to resolve the problem in the case of irrigation.

[37] BM Cecano, Ms. 1605 2459, 4°6198; and Reboulet, "Construction du Canal de Crillon," pp. 41–44.

[38] The *Terres Adjacentes* took advantage of Provence for much more than irrigation. See Villeneuve, *Encyclopédie*, vol. 3, pp. 755–61.

[39] See, for example, Roland Mousnier, *La Venalité des offices sous Henri IV et Louis XIII* (Paris, 1971); ; → Gail Bossenga, "La Révolution française et les corporations: Trois examples lillois," *Annales ESC*, 43 (Mar. 1988), pp. 405–26.

THE REVOLUTION AND IRRIGATION

For 25 years after 1789 there was no increase in irrigated area in Provence and those networks already in use were very poorly maintained.[40] Revolutionary turmoil during the years from 1789 to 1795 was violent in Provence. Moreover, starting in 1792, warfare drained away manpower and drove up the price of labor relative to land, a problem that grew even worse during the Napoleonic period (1798 to 1815). Yet even though the Revolution caused delays in the extension of the irrigation network, it was bringing about institutional reforms that would set the stage for future development, notably the construction of a number of new irrigation canals after 1820.

Institutional reforms, initiated by Revolutionary regimes and continued by Napoleon, would drastically cut the institutional costs of irrigation in the nineteenth century, consolidating all powers of eminent domain in the hands of the central government and destroying the old organizations and institutions that had prevented reforms. In Provence the annexation of the *Comtat* and the abolition of the peculiar status of the *Terres Adjacentes* removed two major obstacles to development of irrigation. For the first time since the early Middle Ages a single authority could decide all issues of property rights in Provence. Beyond the simplification of regional boundaries, the most important single Revolutionary reform was the centralization of legal and political power. Although centralization had been one of the goals of the absolutist monarchy, and although the king had held veto power over virtually all economic activity, he had never been able to eliminate local organizations like the *Parlement*, the *Assemblée du Pays*, the Estates, or even village councils. Centralization during the Revolution eliminated these local organizations and replaced them with a single pyramidic administrative structure headed by the Ministry of Interior. In the case of rights of way, the agent of the government at the local level—the prefect—was now charged with making all decisions.[41] The destruction of all other veto players freed irrigation development from the shackles of strategic behavior. Towns and villages near rivers could no longer refuse rights of way for new irrigation projects simply to protect the market value of their older irrigated land or, even worse, to siphon off part of the profits.

Revolutionary reforms gave prefects complete authority over projects until they were built and removed the judiciary from the planning stages of irrigation, making it difficult for local groups to delay projects through litigation. Local groups could appeal a project only before the prefect,

[40] AD Vaucluse S (Usines et Cours d'Eaux, Cavaillon and L'Isle sur Sorgues). The series S was being classified and sorted at the time I looked through it, thus no precise references can be given.

[41] Jean Petot, *L'Administration des ponts et chaussées* (Paris, 1958), pp. 383–87; Louis Bergeron, *L'Episode napoléonien: Aspects intérieurs* (Paris, 1972), p. 33; Sutherland, *France 1789–1815*, p. 345; and AD Vaucluse S, Usines et Cours d'Eaux.

whose approval was thus sufficient to guarantee the success of an irrigation project. Litigation—when it occurred—did not start until after the canal was built and the social gains were realized. Moreover, conflicts over technical and engineering issues could no longer be litigated but were decided by French administrators. After the Revolution the central administration not only had the power to provide promoters of irrigation with the property rights they needed, it also had the power to enforce the contracts.[42]

After the end of the Napoleonic regime in 1815, and under many different governments, irrigation in southeastern France flourished. State help was considerable, including engineering advice, administrative oversight, and the full power of its newly centralized authority. One form of support, however, was conspicuously absent: the government offered very few subsidies for the development of irrigation. By and large the irrigation canals of the nineteenth century seem to have been paid for by the landowners whose fields were irrigated, further evidence that institutions rather than technology or profits had caused the earlier market failure.

Whether in the case of a small project such as the canal of Plan-Oriental, or in the case of a large project such as the canal of Carpentras, state approval was decisive. The Plan-Oriental canal involved only a small amount of land (800 hectares) and delivered water to fields only in a few villages. The project was quickly approved by the prefect and completed in 1823, less than four years after initiation. In contrast, the canal of Carpentras involved more than 4,000 hectares in many different communities. Although the size of the canal slowed development, the state showed the flexibility of its new power by designing organizations with authority over many communities and many canals. For example, an organization was created that legally grouped all the canals drawing water from the Durance at the site originally used by Cabedan-Neuf alone, thereby allowing an efficient sharing of this desirable site.[43] Because the promoters were able to rely on the support and authority of the national government the Carpentras canal was completed in 1865, less than 20 years from its launching.

The overall success of irrigation in the nineteenth century is striking: more than 16,000 hectares, at least half of all the land irrigated from the Durance by 1875, received water from canals completed between 1820 and 1860. In all, more than 80 percent of the increase in irrigated area between 1700 and 1860 came after 1820.

[42] Fernand Ponteil, *Les Institutions de la France de 1814 à 1870* (Paris, 1965), pp. 30–34.
[43] René Caillet, *Le Canal de Carpentras*, pp. 75–76.

CONCLUSION

Under the Old Regime the division of authority over rights of eminent domain limited the scale of irrigation development. In Provence the political division of authority—a legacy of the Middle Ages—gave ample opportunities to a variety of groups to hold up projects. Villages successfully used this position to extract rents from canal promoters.[44]

Only local irrigation projects could avoid the costs associated with divided authority over rights of eminent domain. As a result, the transaction costs associated with irrigation development increased dramatically when projects crossed authority boundaries. Irrigation promoters were forced to face these transaction costs because the state proved incapable of reform.

The problems of eminent domain were simply not resolved before the French Revolution, which makes it surprising that any irrigation projects were developed before 1789. By contrast, the nineteenth century witnessed substantial growth in irrigation in southeastern France without significant litigation and with much shorter delays than had been customary in the previous century. Between 1820 and 1865 the area irrigated in Provence more than doubled and all the water in the Durance was used. Hence, insofar as irrigation is concerned the Revolution seems to have been a turning point. While the contribution of the Revolution to economic growth still eludes us, it appears that 1789 had a dramatic effect on transaction costs in irrigation.

Appendix

INCREASES IN IRRIGATED AREA

The studies of irrigation by J.-A. Barral offer good data to estimate the increase in total output as a result of irrigation because he investigated irrigated acreage thoroughly for each canal. In 1875 the total irrigated area for the region was about 52,700 hectares, or 18 percent of the total cultivated area.[45] To evaluate total output changes we must know the increase in area irrigated, not only from the Durance (a figure that is available and presented in Table 3), but also from other rivers. The increase in irrigation from other sources is not known precisely, so I present two estimates. The first concerns the impact of the increase in Durance irrigation, while the second estimates the increase in output that would have occurred if irrigation from all sources had grown at the same rate

[44] Veto power was widely used to extract rents from developers in Old Regime Provence; see Baehrel, *La Basse Provence rurale*, pp. 450–56; René Pillorget, *Les Mouvements insurrectionnels de Provence entre 1596 et 1715* (Paris, 1975), pp. 196–207; Maurice Agulhon, *La Vie sociale en Provence intérieure au lendemain de la Révolution* (Paris, 1970), pp. 43–59.

[45] One hundred forty thousand acres. The total cultivated area in the Bouches du Rhône and the Vaucluse was 201,000 hectares (excluding olive groves and vines). Since I was concerned with output that could be increased by irrigation, I excluded both olives and vines from my measure of total cultivated area. J.-A. Barral, *Les Irrigations dans le Vaucluse* (Paris, 1876), pp. 323–34; idem, *Les Irrigations dans les Bouches du Rhône*, pp. 83–87, 511–12.

TABLE 3
INCREASES IN AREA IRRIGATED FROM THE DURANCE
(in hectares)

Region	Periods			
	1100–1700	1700–1789	1790–1820	1820–1860
Vaucluse	3,835	2,253	0	9,105
Bouches du Rhône	10,624	1,765	0	8,211
Total	14,459	4,108	0	16,316

Sources: See Appendix text; Jean-Auguste Barral, *Les Irrigations dans le Vaucluse* (Paris, 1876), pp. 323–34; and Jean-Auguste Barral, *Les Irrigations dans les Bouches du Rhône* (Paris, 1875), vol. 1, pp. 86–91, 511–12.

as Durance irrigation. Since irrigation at least doubled output we know that the increase in output will be close to the ratio of newly irrigated area to total cultivated area. The early nineteenth-century canals added 16,314 hectares of irrigated land from the Durance compared with 3,211 for the eighteenth century as a whole. The Durance's increase alone would have led to a 7.7 percent increase in total output for Provence. If non-Durance irrigation witnessed the same growth, total output would have increased by about 12 percent.

LAND PRICES

Sampling and Sorting

At least four notarial *études* (practices) were active in Cavaillon between 1700 and 1855. However, gathering data from all land contracts for Cavaillon from 1700 to 1855 would have taken at least two years' research. Sampling was therefore necessary. The data represent a complete, quinquennial sample of both land-sale and land-rental contracts from one *étude* from 1700 to 1855. Up to 1720 I sampled two *études* because the first had too few land contracts. The total sample contains 1,781 observations. To obtain both an irrigated- and a dry-land price series, it was necessary to distinguish sales and rental of irrigated land. Before 1800 such sorting was relatively easy since the contracts all contained detailed information about the quality of the land. After 1800, however, notaries ceased recording such information regularly. I therefore relied on location data to distinguish between irrigated and dry land after 1800. Such sorting by location is imperfect, making the irrigated series a downward-biased estimate of irrigated land prices and the dry series an upward-biased estimate of the price of dry land after 1800.

Constructing the Series

The land prices were estimated with a simple procedure that allowed me to use data both from rental contracts that predominated before 1789 and from sales contracts that predominated after the Revolution. For rental contracts the value of a transaction was computed by capitalizing the rent using the interest rate. Such a procedure ignores capital gains; thus the price series for dry and irrigated land will be downward-biased. If anything this will reduce the absolute value of the difference in these prices, which will bring down the estimated rates of return. For sales, the value of land was simply the price. For each year for each type of land (dry or irrigated), average prices were

TABLE 4
PRICE SERIES FOR PROVENCE, 1700–1855

Date	Daily Wages (unfed, in francs)		Land Prices (in francs per hectare)	
	Unskilled	Skilled	Dry	Irrigated
1700	0.61	1.00	511	2,153
1705	0.77	0.90	814	2,730
1710	0.76	1.07	1,080	2,201
1715	0.74	1.00	851	2,819
1720	0.75	1.00	1,510	2,590
1725	0.74	1.12	939	2,297
1730	0.79	1.11	1,031	2,202
1735	0.76	1.22	1,598	2,407
1740	0.73	1.10	1,320	2,355
1745	0.92	1.25	1,538	2,477
1750	0.88	1.14	1,827	2,694
1755	0.94	1.25	1,827	2,694
1760	0.76	1.30	1,934	2,857
1765	0.93	1.25	1,410	2,867
1770	1.09	1.25	2,361	3,854
1775	1.12	1.60	2,081	3,055
1780	1.12	1.50	2,203	5,003
1785	1.18	1.50	1,604	4,328
1790	1.14	1.50	2,756	3,271
1795			4,365	6,309
1800	1.66	2.41	1,910	2,963
1805	1.15	2.24	2,044	5,438
1810	1.59	2.16	2,698	4,097
1815	1.61	2.43	2,640	3,831
1820	1.78	2.27	2,420	3,677
1825	1.74	2.22	2,985	5,100
1830	1.73	3.18	2,590	4,411
1835	1.89	3.00	2,450	4,469
1840	1.78	2.60	2,399	5,149
1845	1.77	3.00	2,621	5,192
1850	1.88	3.00	2,679	5,400
1855	1.86	3.00	2,900	5,470

Sources: See text, fn. 13, and the Appendix text.

calculated for each type of contract as the sum of the value of all transactions divided by the total area sold.

WAGES

The sample contains 851 bills of wages for 13 professions, covering roughly 150 years for a total of over 60,000 man-days. The bills were sorted into skilled and unskilled and the reported wages are the ratio of the total wage bill for a given year divided by the total number of days worked. To the extent that canals were built solely in the winter—when wages were lower than average—the rates of return would be even higher than estimated. Yet since winter and summer wages seem to move in tandem, the trends in the wage bills should not depend on the aggregation procedure. Since we care most about the trend in benefit-cost ratios, the procedure used here seems adequate. Table 4 presents both wage and land prices.

TABLE 5
HYPOTHETICAL BENEFIT-COST RATIOS FOR IRRIGATION PROJECTS

Date	Cabedan-Neuf I	Cabedan-Neuf II	Crillon	Plan-Oriental	Carpentras
1700	3.85	3.20	3.66	3.82	3.13
1705	4.01	3.45	3.91	4.34	3.33
1710	2.06	1.83	2.06	2.27	1.75
1715	3.96	3.42	3.88	4.24	3.30
1720	1.91	1.80	1.99	2.29	1.71
1725	2.57	2.24	2.53	2.74	2.17
1730	2.14	1.88	2.12	2.32	1.82
1735	1.29	1.20	1.34	1.49	1.14
1740	1.82	1.67	1.87	2.07	1.59
1745	1.08	0.92	1.04	1.23	0.88
1750	1.30	1.23	1.36	1.58	1.16
1755	1.22	1.14	1.27	1.45	1.07
1760	1.33	1.28	1.42	1.60	1.20
1765	2.24	2.02	2.26	2.53	1.93
1770	1.96	1.92	2.11	2.48	1.78
1775	1.15	1.06	1.18	1.33	1.01
1780	3.31	3.10	3.44	3.93	2.92
1785	3.43	3.04	3.42	3.82	2.92
1790	0.56	0.55	0.60	0.70	0.51
1795					
1800	0.87	0.75	0.85	0.92	0.70
1805	3.02	2.65	3.00	3.27	2.49
1810	1.19	1.09	1.22	1.37	1.02
1815	0.95	0.85	0.96	1.06	0.80
1820	1.03	0.91	1.03	1.14	0.86
1825	1.71	1.57	1.75	1.99	1.49
1830	1.29	1.14	1.28	1.37	1.10
1835	1.46	1.27	1.44	1.55	1.24
1840	2.18	1.92	2.16	2.36	1.86
1845	1.88	1.67	1.87	2.02	1.62
1850	1.92	1.69	1.91	2.07	1.63
1855	1.81	1.62	1.82	1.98	1.57

Sources: Tables 1 and 2.

CANAL CONSTRUCTION ACCOUNTS

Number of Man-Days

Canal construction accounts rarely itemized costs beyond excavation (*terrassement*) and skilled construction (*ouvrages d'arts*). As the former was done by unskilled labor, I divided those costs by the wage for unskilled labor for the period in which the project was carried out to get an an estimate of the quantity of labor employed. To simplify the calculation of the rates of return, I assigned all skilled construction and administrative costs to skilled labor. Skilled construction involved the building of bridges for roads over canals and aqueducts for canals over small rivers and valleys. Such jobs were clearly the domain of skilled masons. Nonlabor inputs were also assigned to skilled labor, because the primary input of canals other than labor was quarried stone. Quarrying was an extractive industry that required only skilled labor and some transportation. Thus the cost of quarried stone should closely follow the price of skilled labor. The sum of nonlabor inputs, skilled labor, and administrative expenses was divided by the skilled wage to get an estimate for the number of skilled man-days.

TABLE 6
HYPOTHETICAL INTERNAL RATES OF RETURN FOR IRRIGATION PROJECTS

Date	Cabedan-Neuf I	Cabedan-Neuf II	Crillon	Plan-Oriental	Carpentras	Interest Rate
1700	157.5%	84.6%	120.4%	156.1%	50.1%	5.36%
1705	166.0	102.4	127.2	185.0	54.1	5.15
1710	77.9	35.4	68.8	94.3	30.1	5.30
1715	157.3	93.2	121.0	173.0	51.5	5.30
1720	61.3	27.9	58.2	86.5	25.8	4.62
1725	95.5	45.0	80.5	105.0	34.8	4.62
1730	77.3	32.4	67.6	89.4	29.2	4.94
1735	25.3	−3.7	27.6	41.3	10.2	4.94
1740	55.6	19.0	52.3	71.3	22.7	4.90
1745	35.5	3.1	35.8	50.9	14.4	4.90
1750	26.7	−0.8	29.6	47.5	11.3	5.51
1755	21.4	−6.7	24.1	38.8	8.3	5.51
1760	32.6	6.0	35.7	57.5	14.7	5.04
1765	88.5	47.1	77.6	111.0	34.4	5.04
1770	64.0	35.9	62.1	98.4	28.7	5.03
1775	17.1	−11.1	19.6	32.6	5.8	5.03
1780	127.1	85.3	106.7	164.2	48.0	5.01
1785	138.5	84.7	111.2	161.0	48.5	5.01
1790	−36.3	−53.4	−44.2	−24.0	31.2	6.87
1795						
1800	−6.9	−36.5	−12.1	−0.9	10.8	9.30
1805	93.5	39.8	77.8	98.6	32.8	8.70
1810	12.7	−17.4	13.4	23.1	2.4	6.15
1815	−7.8	−10.6	−10.2	15.3	−8.3	7.40
1820	17.6	−12.5	18.9	29.9	5.3	6.70
1825	58.4	24.8	55.7	81.5	24.6	5.09
1830	49.7	15.2	47.9	67.8	20.4	5.16
1835	58.9	21.1	54.6	75.4	23.5	4.33
1840	89.3	44.7	77.3	107.4	33.9	4.58
1845	59.2	17.7	53.6	67.4	22.9	3.62
1850	66.6	24.2	59.6	77.1	25.7	3.57
1855	61.4	21.9	56.1	76.2	24.1	4.41

Sources: Tables 1 and 2.

Land Consumed by Canals

The main canal of Carpentras, the largest canal in my sample, was only 7.5 meters wide. Including the embankments, it occupied an area less than 17 meters across for the first quarter of its length. The rest of the main canal occupied an area less than 10 meters wide, and its branches were even smaller. Other canals were less than 4 meters at their widest and their branches were much smaller than that. I assumed that all canals required a band of land 15 meters wide and the length of the canal and its main branches. This simplifying assumption, by reducing the estimated profits, can only strengthen any finding that irrigation was profitable before 1760.[46]

[46] Caillet, *Canal de Carpentras*, pp. 194–212.

Uncounted Revenues

I disregarded certain revenues accruing to canals that are difficult to estimate. These revenues came from the sale of water-power rights on the canal to mill owners. To be sure, mills were an important source of revenues for some canals. They brought in revenues equal to one-sixth of maintenance costs on the canal of Crillon. A mill was worth above 20,000 livres in the eighteenth century or more than 5 percent of the cost of a small canal.[47] The size and value of mills varied greatly. Moreover, the value of a mill is not a good indicator for the rent of the fall, which is what accrues to the canal owner. Therefore one would need not only the rental contracts of the mill but also their agreement with the canal to know what they paid for the fall. The archival research effort to secure rental contracts would thus be very large for little gain. Obviously the omission will push my hypothetical rates of return downward.

Maintenance Costs

Some maintenance costs already appear in the price of irrigated land. Indeed the price of a particular piece of irrigated land is equal to the discounted stream of profits from using that land minus the capitalized value of whatever maintenance costs are assessed on that land. If all irrigated land were assessed uniformly there would be no need to count maintenance costs, but such uniformity was far from prevalent in Cavaillon, where each canal had a different organization dealing with maintenance. Each organization assessed landowners on a yearly basis for contributions, but it did not assess land uniformly, either over time or across parcels. Thus the land price series reflect only maintenance costs as assessed by the institutions governing canals in Cavaillon. It is clearly wrong to assume that the maintenance costs already affecting the irrigated price series are the correct ones for all projects. As a result it seemed best to assume that the price series reflect the discounted future revenues from land and to account for maintenance costs explicitly. To do this, and to simplify the calculation of internal rates of return, I assumed that the promoters created a sinking fund to pay for the future maintenance costs.

[47] AD Vaucluse, I doc. 221. See also AD Vaucluse, S, Usines et Cours d'Eaux (Avignon, canal de Crillon, 1820).