The Development of Irrigation in Provence: 1700-1860
The French Revolution and Economic Growth.

Jean-Laurent Rosenthal
Department of Economics
U.C.L.A.
Los Angeles Ca 90024

UCLA Dept. of Economics
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ABSTRACT

In order to assess the constraint on economic developement in France prior to 1789, this paper investigates the causes of the Old-Regime's failure to develop irrigation by first considering whether irrigation was social profitable. Because of the apparent high returns to an eighteenth-century extension of the irrigated area, the institutional obstacles to the construction of new canals are explored. The political division of authority allowed a variety of groups to hold a project up by using their veto power over rights of eminent domain. As a result, the transaction costs associated with irrigation development increased dramatically when projects crossed authority boundaries. Irrigation developers were forced to face these transactions costs because the state proved incapable of reform. The costs of securing rights of eminent domain were reduced by a series of institutional reforms enacted during the French Revolution. Thus, we should reconsider our understanding of the importance of the French Revolution in light of its significant consequences for economic growth.

I. Introduction

Using data drawn from a French province, this paper suggests that legal and institutional impediments to economic development may have been very severe in Old-Regime France. The arid climate of the region under study, Provence in southeastern France, hampers agriculture production greatly. Yet irrigation, a well known remedy to the ecological deficiencies in water,[1] grew only marginally during the period 1700-1789. After 1820, in contrast, there was a veritable 50 year boom in canal construction which resulted in the doubling of the irrigated area. This paper investigates the potential causes of the Old-Regime's failure to develop irrigation by first considering whether irrigation was social profitable. Because of the apparent high returns to an eighteenth-century extension of the irrigated area, the institutional obstacles to the construction of new canals are explored. This paper suggests that the legal shackles imposed on the French economy by the Old-Regime may have been very severe. Moreover, these shackles were broken by a series of institutional reforms enacted during the French Revolution. Thus, we should reconsider our understanding of the importance of the French Revolution in light of its significant consequences for economic growth.

The issue of the French Revolution's contribution to economic growth has long been recognized by historians and economic historians. Most have viewed the French Revolution either as testimony to the Old Regime's inability to survive in the world of the industrial revolution, or as the unfortunate result of poor political calculations on the part of the nobility or the king's ministers.[2] Hence they have focused on the causes of the Revolution while as Alfred Cobban[3] argued the true measure of such an event probably lies in its consequences. 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.[4] The paper focuses on the legal constraints on the development of irrigation in order to deepen our understanding of which factors were responsible for the absence of agricultural growth. The narrowness of the topic at hand--irrigation in Provence--is dictated by the need for precise knowledge

on 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 the problems of the Old-Regime economy would miss the details that might explain the diversity of regional performance and failure. The paper's conclusions, however, hold for most of eighteenth-century France because any investment project that featured externalities would plagued by the same problems that plagued irrigation. In fact the problems of irrigation development are imbedded in the general problem of growth in an economy where rent-seeking is prevalent. The property rights (*privileges*) of Provencal organizations must be made precise in order to present a convincing case that they held back the development of irrigation, but they are in fact indicative of the more general constraints on investment in Old-Regime France.

The second section presents the issue an argues that irrigation networks built after 1765 significantly raised agricultural output in southeastern France. The third part confronts the issues of technology and credit and demonstrates that such irrigation networks could have been built profitably prior to 1765. The fourth part analyzes the causes of the Old-Regime market failure: divided authority over rights of eminent domain. The fifth section examines the institutional changes associated with the French Revolution and the subsequent development of irrigation in the nineteenth century.

II. Irrigation and Provencal Agriculture

If considered only from a purely geographic point of view Provence[5] would be the area in France where the development of an irrigation network should have had the greatest impact. Provence is one of the more arid regions of France and one were rain is most unevenly distributed over the year. As a result, years where rainfall is negligible after the first of June are frequent, thereby restricting agricultural production to grains, grapes and olives. Irrigation allows farmers to grow crops which require both the warmth of the summer and significant amounts of water such as peas, beans and other vegetables. Another benefit of irrigation is that the water of the Durance river (the main source of irrigation water), is very silty and acts as a natural fertilizer. The silt from the Durance was sufficiently abundant that eighteenth-century farmers could avoid the biennial fallow on irrigated plots.

The abandonment of the fallow alone indicates how dramatic an impact irrigation could have on total output. On irrigated land Provencal farmers could double their output--by not fallowing--and grow a wider variety of crops than on dry land. Thus, the value of output may have more than doubled in actuality as a result of irrigation.[6] Using sharecropping contracts to trace the increase in the quantity of labor and capital applied to the land as a result of irrigation allows me to compute an estimate of total factor productivity change, a measure of productivity change that takes into account the fact that more labor and capital were applied to irrigated land than to dry land.[7] Total factor productivity per acre would have risen by 30 to 40 percent as a result of irrigation. Thus, from the point of view of a farmer and more so from that of a landowner irrigation would have represented a significant increase in output.

The Old-Regime royal government may have been less concerned with increasing production on specific plots of land than with raising regional agricultural output. Data from the 1870s allows me to estimate the change in agricultural output as a result of the development of irrigation after 1760 (see the Appendix for details). Had the canals planned or proposed under the Old Regime and realized before 1860 been built in the eighteenth century, the increase in total output in the region would have been about seven percent. An output change of seven percent is a far cry from the 100 percent per acre change but it would have significantly eased any short-term Malthusian constraints on the population, the very problem that concerned so many government officials. A qualitative examination of the climate, 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 1765, when the development of irrigation began to accelerate. Indeed, some of the canals of southeastern France dated back to the Middle Ages.[8] Ignorance could not have been the obstacle to irrigation under the Old Regime because a number of projects were proposed between 1700 and 1789. Thus we must look elsewhere to explain why it developed so slowly before 1789.

III. Profitability

Why were irrigation canals so infrequently built prior to 1789? The simplest answer to this question is that the returns to irrigation were low before the Revolution and rose thereafter because of technological change, better credit markets or relative price changes. This section confronts each of this potential answers in turn. Using data from projects built both in the eighteenth and nineteenth centuries, we shall see that neither profits nor techniques, nor even credit were the determining factor in the timing of irrigation development. Let us must first examine the issues of technical change and credit and present the data collected to examine the issue of profits.

III.1 Technology

The technology of irrigation raises three important issues. First, we must define what were the important inputs in canal construction. Second, we must determine whether the techniques of irrigation canal building changed between 1700 and 1860. If there were significant changes in canal construction techniques, then the effects of that change on costs would have to be taken into account when estimating hypothetical rates of return. Third, we must examine the risks involved in canal building. If risks were high, premiums might be necessary to attract investors to the development of irrigation networks .

In the eighteenth and early-nineteenth centuries the technology of irrigation was quite simple. Throughout the period, the primary inputs to canal construction were land, unskilled labor, and skilled labor. Moreover irrigation canals were unlined, and all water flowed by gravity. The technology used to build irrigation canals was very simple, and had little to do with the sophisticated techniques that evolved with the rise of transportation canals. Indeed by the middle of the eighteenth century transportation canals in France involved locks, dams, bridges and complex water management.[9] None of these techniques affected irrigation, even in the nineteenth century. One reason was that as late as 1870, much more land could have been irrigated using such simple technologies, had there been water in the Durance to draw. Thus, except for a few bridges where skilled labor and other inputs were required for stone masonry, irrigation projects thus required mostly unskilled labor for digging ditches.

As one might gather from the simplicity of the inputs, technical change in irrigation canal construction was insignificant. For irrigation canals, construction techniques changed practically not at all until late in the nineteenth century. Other techniques were available, but they were not used in irrigation construction because they were too costly. The technological stasis in canal construction may well have extended back well before the eighteenth century. The methods used in the years from 1700 to 1860 were technologically similar to those used in the thirteenth century to build the canals of Saint-Julien and l'Hopital, or in the sixteenth century to build the canal of Craponne.[10] From the thirteenth to the nineteenth century, all these canals were unlined dirt ditches, where water flowed by gravity alone. Stone masonry was used only for bridges. The only dams in use, which captured the water from the Durance river, were flimsy dirt levees, and they had be rebuilt frequently. These dams only diverted part of the flow of the river but made not attempt to retain water behind a reservoir.

The returns to agricultural development could probably not have supported very expensive and innovative technologies. In contrast to the low levels of technological sophistication utilized in agricultural projects stands a set of urban projects that overlap both geographically and temporally with those under study. One of these projects, the canal of Marseille (1840-1848), a joint urban and rural water supply project, offers a good example of the technologies that were available in the middle of the nineteenth century but that were not used in agriculture. The canal of Marseille featured a large dam and a permanent reservoir, many bridges, and was underground for 25% of its length. The project was financed by the city of Marseille, which attempted to sell excess water to landowners. The city also wanted the 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.[11]

The final issue concerns technological risk. Although irrigation technology did not change, it is possible that over time learning by doing led to smaller engineering errors. The resulting reduction in technological risk would increase the viability of projects by reducing the size of the risk premiums

demanded by investors. Yet, technological risks--the risks associated with the construction phase of the project--were 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 demanding technologically and thus riskier. Irrigation projects were by contrast very simple, even when there were unanticipated delays or higher than expected costs.[12]

It thus appears that between 1700 and 1860 technological change in irrigation canal construction was limited, and the canals developed from 1760 to 1860 are all similar technologically. Technological risk did not threaten irrigation projects. Neither risk nor technology therefore constrained the supply of irrigation. Why then did water remain unused until past the 1850s? The answer clearly lies beyond the simple issue of technology.

III.2 Credit

Since the construction of irrigation canals involved significant outlays of capital, credit was very important to irrigation. One reason for the lack of canal building in the eighteenth century might therefore be insufficiently developed capital markets. This argument appears plausible because Old-Regime France lacked a well-developed, centralized, government credit market, and there were nearly no banks,[13] however, the insufficient development of credit markets did not block the expansion of the irrigated area of Provence. There were extensive credit networks that functioned remarkably well for credible debtors. Organizations and individuals with enough collateral to warrant a loan seem to have found many willing creditors throughout the eighteenth century. Moreover the credit demands of most irrigation canals were very small relative to the credit demands of the several hundred Provencal villages that borrowed extensively during the seventeenth and eighteenth centuries. One set of credit markets that were very active in rural France, could have provided significant sources of capital for irrigation developers. These markets were based on mortgages of land and other immovables, which had low default risk. Eighteenth-century developers were often very large landowners who could have

raised large amounts of capital on the mortgage markets. If there was a credit problem associated with irrigation canals it was probably not with the supply of credit; rather it may have been with the collateral offered by canal promoters--an institutional problem.[14]

Furthermore, in the case of southeastern France, there were at least two other sources of funds for irrigation projects: Jews and the high nobility. First, Jews were directly involved in making loans to at least one developer in the 1780s. These loans did not have the collateral of land, and the developer paid an interest rate double that of the mortgage rate--10 to 11% as compared to 5%. Second, the high nobility was also able to finance projects directly in the case of many of the smaller projects. The high nobility put its vast wealth resources at the disposal of canal developers (in other instances as well) perhaps because irrigation canals did not carry the stigma attached to many other forms of investment.[15] Therefore, it seems there were sufficient sources of capital (though not necessarily market sources) to carry out the irrigation projects. If credit was not directly the cause of the failure or irrigation development what then?

III. 3 Data

The lack of irrigation development under the Old-Regime could be attributable to low profits. To establish that profits would have been sizeable before 1760, I have estimated the level of profits that projects, realized after 1760, would have earned had they been started earlier. The results will be presented under two forms: rates of return and benefit-cost ratios. The calculations require three kinds of data: first, price series for the inputs and outputs of canal construction; second, factor shares for each canal; and third, an interest rate series because the project occur over a number of years.

Canal and other construction accounts do not break down the costs in a very detailed fashion (except in the case of labor where the accounts are more specific), thus it is difficult to get factor shares or time series of prices for such things as quarried stone, lime, wood and other material inputs. However since material inputs other than labor were only used on bridges and other necessary buildings, land and labor composed nearly all the costs of canal construction. Therefore, wages will be

our deflators of the input costs of canal construction other than land. Our deflator for the price of output (social return) will be the difference between the price of irrigated land and the price of dry land; since land is the only input in fixed supply all the net output gain from irrigated land should accrue to the owner of the land. Given these assumptions one can compute the hypothetical cost benefit-cost ratio, R^t, had the project started in year t and taken T years to complete:

$R^t = \frac{N(p_i - p_d)\,(1+r^t)^T}{\sum_{j=0}^{T} (d_u\, w_u{}^t + d_s w_s{}^t + np_i)(1+r)^j + \frac{1}{r^t}m}$. Where N is the number of acres of land irrigated; p_i (p_d) the price of irrigated (dry) land in year t; d_u (d_s) the number of man days of unskilled (skilled) labor used in the j^{th} year of construction ; $w_u{}^t$($w_s{}^t$) the daily wage of unskilled (skilled) labor in year t; n the amount of land consumed by the canal itself; m the expected yearly maintainance costs and r^t the interest rate in year t. The hypothetical internal rate of return is simply the r^{*t} that sets R^t to 1.

I was able to construct two different wage series using data collected from the records of various organizations in Avignon, a large town in the middle of the area under study.[16] The labor data consists of wage bills from the account books of religious and municipal organizations for unfed labor.[17] The data are relevant for this study because they are drawn from the very professions involved in canal construction and maintenance. Religious institutions, whose account books I used, owned some medieval canals and they hired labor by the day for maintenance work on these canals. The data have been sorted into two series: skilled and unskilled workers (see figure 5, at the end of the text). The first, unskilled labor, is composed of agricultural laborers, road gangs and levee maintenance workers. The second is composed of skilled workers: masons, carpenters, miners, and gang bosses.[18]

The data for the land price series are taken from a sample of land-sale and land-lease contracts that were negotiated between 1700 and 1855. The sample comes from the archives of public notaries. To be recognized in court, French private contracts had to be filed with a *notaire* who not only witnessed the contracts but kept copies. These copies were preserved in yearly-bound volumes and form a very rich but highly disorganized source of micro-level data for economic historians. The

sample was taken from 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. 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 land irrigated than other areas should lead to a downward bias in the price of land irrigated and thus to an underestimate of potential canal revenues.[19]

To calculate hypothetical profits I also needed data on the specific costs and revenues of the canals that were built in both the eighteenth and the nineteenth century. The costs include both the amount of labor expended and the amount of land used. The data is 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, Carpentras). While there is insufficient data to estimate profit from most other eighteenth- and nineteenth-century projects, the set of canals for which data is available are representative of all canals built in the eighteenth and nineteenth century, in terms of size, location, and timing. The canal of Carpentras is as large as any other canal in Provence and the smaller Cabedan, Crillon and Plan Oriental are representative of most other projects.[20] Tables 1 and 2 display in condensed form all the project specific data used in the construction of hypothetical profit streams.

[Table 1 about here]

[Table 2 about here]

The only other data necessary are interest rates. Unfortunately, time series of interest rates are lacking for the eighteenth century. One possible source of data are notarial records because land sales contract often contained mortgage rates. Since land sales were rarely paid in full, the seller would extend a mortgage to the buyer and the mortgage was often directly included in the sales contract. The mortgage rates from these land sales contracts remain stable at 5% through the period 1700-1855. An alternative method of estimating interest rates involves shadow interest rates constructed from nineteenth-century French data and from British consol rates that span the period.[21] I ran the

calculations of rates of return and cost-benefit ratios using both sets of interest rates, and the results do not depend on which series of interest rates is used in the calculations.

III.4 Hypothetical Profits

I estimated both benefit-cost ratios and internal rates of return. The conclusions are identical and do not depend on which interest rate series was used for the calculations.[22] All projects were profitable during nearly the entire period under study. But, the projects were more profitable in the early eighteenth century when they were not carried out than in the nineteenth century when they were. Although some projects are always more profitable than others, changes in profit rates are similar for all projects and the profitability of an irrigation canal does not seem to depend on the scale of the project. Profits for any project vary a lot from one estimate to the next but the years where the benefit-cost ratio's are less than 1.2 are rare (less than 20% of the years) suggesting that is the uncertainty might have concerned the magnitude of profits rather their existence. The dispersion of rates of return and benefit-cost ratios seems due to changes in the increase in the value of land as a result of irrigation (75% of the variance of the benefit-cost ratios is explained by a regression of the ratio on land prices). Because the hypothetical profits of projects built under the Old Regime are similar to those of projects built after 1820, it is unlikely that changes in technology played a major role in irrigation development. Otherwise the later projects should have been much more profitable.

[Table 3 about here]

The highest profits come in the early eighteenth century (1700-1730). In fact, the projects were hypothetically more profitable during this period than during any subsequent one, as table 3 above shows. In the middle of the eighteenth century, (1735-1755) projects were less profitable (but not unprofitable) than at any other time except for the Revolutionary period. Yet a number of projects built after 1760 were proposed during this period, suggesting that investors, at least, found it profitable to participate in irrigation development. The last decades of the Old Regime (1760-1785) show high internal rates of return and high benefit-cost ratios. The rates of the late eighteenth century

were in fact on average higher 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 hypothetical rates of return all suggest that low rates of profits cannot explain why more irrigation canals were not built before the late eighteen century. The presence of significant profits through most of the eighteenth century, and in particular during the years 1700-1730 suggest that changes in relative prices were not responsible for the late development of irrigation in southeastern France. During most of the eighteenth century, rates of return were in fact higher than those of the nineteenth century. Yet irrigation development was much more limited from 1700 to 1789 than it was from 1820 to 1860. Some sort of a market failure in the supply of irrigation must have been at work in the eighteenth century. Indeed, despite the fact that hypothetical rates of return before 1760 were well above both the estimated interest rate or the mortgage rate, no canal was built before that date. The discrepancy is even greater before 1730. The market failure cannot be ascribed to a lack of acumen on the part of eighteenth-century French investors, for as we shall see, entrepreneurs, landowners and the wealthy elites proposed a number of irrigation projects in this period. Even in the period of lower profits (1730-1755) nearly all these projects would have returned more than four times the rate of interest and nearly three times the customary mortgage rate of 5%. It is no wonder then that a large number of entrepreneurs attempted to develop irrigation networks. There was money to be made in this activity.

Contemporary Provencal landowners, seignors and politicians were not blind to the economic opportunities represented by irrigation. In fact, the very magnitude of entrepreneurial activity is striking when it is contrasted with the failures endured by canal promoters throughout the eighteenth century. Every canal built after the Revolution had a serious promoter before 1789 who had expended considerable resources attempting to secure all the authorizations needed to build the canal. These promoters failed overwhelmingly, if we measure success as the ability to build a canal and earn a

profit. The failure rate remained very high, even if we only demand that a canal be built. Indeed, less than 10% of the acreage planned before 1789 and completed before 1860 was irrigated before the Revolution. Simple economic arguments cannot explain the failure of irrigation development under the Old Regime or its success after the Revolution. Instead one must examine the institutional constraints imposed on Provencal builders by the peculiar division of power that characterized the Old Regime.

III. Institutional Failure: Eminent Domain and Rent-Seeking

What blocked the construction of irrigation networks? The failure of the supply of irrigation had multiple causes. Here I explore the most important: division of authority over rights of eminent domain.[23] First, I outline the history of institutional divisions in Provence. Second, I provide an explanation of why irrigation projects could be held up by the division of power. Third, I examine the historical consequences of the division of power under the Old Regime through specific examples drawn from canal histories.

The political and judicial authority in southeastern France in the eighteenth century can be best explained in terms of the medieval history of Provence. Provence in the early Middle Ages was part of the Holy Roman Empire, but by the fourteenth century it had become virtually independent. The region was then divided into three distinct areas that led to three different Old-Regime judicial and political systems: the *Comtat Venaissin*, the *Comté of Provence*, and the *Terres Adjacentes*. The Old-Regime *Comtat Venaissin* (hereafter the *Comtat*) is geographically equivalent to the present day Vaucluse. The western half of the *Comté of Provence* (hereafter the *Comté*) and the *Terres Adjacentes*, make up what is now the Bouches du Rhone. The existence of three different sets of institutions was a legacy of medieval state building. The most important phase of this process was the division of Provence between the Pope--whose share was the *Comtat Venaissin*--and the counts of Provence who controlled the *Comté* of Provence. In the late fifteenth century, the king of France inherited the *Comte'* and the *Terres Adjacentes*. The *Terres Adjacentes* were a set of administratively independent communities that included Marseille, Arles and a number of villages on the border

king, communities, and the *Parlement* of Aix that exercised certain judicial powers in the *Terres Adjacentes.* In practice, the uncertainty of authority gave both local institutions and the king veto power over irrigation projects.

Beneath these regional authorities there were certain local organizations that could have reduced the transaction costs associated with irrigation. Each village or town had at its head a council headed by three consuls. Because developers could write contracts with the consuls, this form of municipal organization made it easier for them to bargain with villagers. The same municipal organization, however, also made strategic behavior easier for villages, especially in areas like the *Terres Adjacentes* where regional and national authority was very limited. Moreover because village government was well organized, it was very costly for central authorities to impose projects like irrigation canals.

The inability of the king or any regional authority to discipline local organizations allowed many villages to hold up irrigation projects in order to bargain for rents. Because it involved both economies of scale and significant geographical specificity, irrigation was an easy prey for rent-seeking villages. The economies of scale of irrigation had to do with the fact that canals were networks. The costs involved with building the main canals did not rise as quickly as the irrigated area increased. Moreover, because canals relied on gravity to move water, for each area there was usually a single economical drawing site from the river. As a result villages close to the Durance could credibly threaten irrigation projects with either much higher cost or insurmountable engineering problems if they refused to grant rights of eminent domain. In such a situation irrigation promoters were faced with dire alternatives, they could give up. They could pay off the villages or they could bear the much higher cost of less economical routes. Most often, however villages were in a position of such strength that promoters could only give up or give in.

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 such behavior--rent-

seeking--was widespread under the Old Regime. From the *Epices* of the judicial officers and the monopolies of craft guilds, to the selling of many other privileges by the crown, rent-seeking was commonplace under the Old Regime.[27] Ironically, in the case of irrigation, the greatest rent-seeker of them all, the crown, was allied with the promoters of development against local powers that were holding the projects up for ransom. As we shall see below in the example of rights of eminent domain, the crown proved powerless to resolve the problem in the case of irrigation.

One would presume that the political border that ran between *Comtat* and *Comtè* was the root cause of the institutional problems, but in fact the two territories were divided by the Durance river. Thus most canals were either in the *Comtat* or in the *Comtè* even though nearly all of them drew water from the Durance. So most *Comtat* affairs were strictly *Comtat* affairs and the same was true in the *Comtè*. Moreover the problems of eminent domain were sufficiently important within each political division that we can ignore the effect of the Pope's ownership of the *Comtat*. Let us, for example, consider rights of eminent domain in the *Comtè*. Since any canal on the southern side of the river would irrigate land mostly in the *Comtè*, the king, the Estates and the *Parlement* were also veto players; however, the need to cross the *Terres Adjacentes* added a further cost. In the *Comtè*, the best sites to draw water from the Durance were in or let into the *Terres Adjacentes*. Thus the organizations that regulated eminent domain in the *Terres Adjacentes* had the ability to veto projects.[28] In the *Terres Adjacentes* the king of France, in theory, decided all issues of eminent domain. Each local community, however, had effective veto power over eminent domain rights as well. In the Middle Ages the *Terres Adjacentes* had been autonomous and had in fact decided issues of eminent domain alone. Although the extent of local autonomy was uncertain and subject to continual disputes during the eighteenth century, the communities were well-organized and could credibly threaten to sue anyone who did not secure rights of eminent domain from them.

The credibility of the *Terres Adjacentes* threat had been verified at least once in the sixteenth century when Adam de Craponne--a Provencal nobleman and an engineer who enjoyed the favor of the

king and had solid political support from both the *Parlement* and the Estates--attempted to build a large irrigation canal in the *Comtè*. He secured a grant from the king to draw water from the Durance, and a grant of eminent domain rights from the Estates. Both were registered in the *Parlement.* His grant for water made it necessary for his canal to go through a number of *Terres Adjacentes* communities. They, however, did not come under the jurisdiction of the Estates as far as eminent domain was concerned; and they delayed the project until Craponne gave them what they wanted: free access to all the canal's water that they desired.[29]

Despite these outlandish concessions, Craponne not only proceeded to build his canal in 1520 but he also succeeded in selling a number of irrigation rights below the *Terres Adjacentes.* In dry years, however, the *Terres Adjacentes* communities used up most of the canal's capacity, and with no water to deliver, Craponne had to 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 the villages in the *Terres Adjacentes*, 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. The example of Craponne and his sixteenth-century canal underscore the costs of securing adequate rights of eminent domain in Provence.

Only four small projects were completed in the late eighteenth century. Three of the small canals were in the *Comtat* and the fourth was in the *Comtè*. Each of the four projects distributed water to, at most, a few communities. They did not cross any important institutional boundaries and remained small because larger projects were plagued by a variety of institutional problems, and even among the four projects, delays and transaction costs rose with size.

The two smallest canals, Janson and Cambis, were only a few kilometers long, and they faced only minor transaction costs. Both were entirely financed by the principal landowner in the areas they irrigated. The Marquis of Janson and the Duke of Cambis, the two noblemen who built the canals, wanted to irrigate their estates, which were very large. The Marquis and the Duke both maintained

because of the extreme division of authority in the region.

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 seignors and religious institutions, all of whom held the project up for ransom by attacking it in court. The most important suit concerned Crillon's right to cross other canals, an absurd point of law in terms of economic growth but potentially a very profitable one for the owners of the other canals. The suit was brought by the Duke of Gadagne, lord of Vedene, one of the communities traversed by the canal. Gadagne contested both the right to cross Vedene without his authorization and the right to cross his own irrigation canal in Vedene. 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 long after the French Revolution.[32]

The case of the canal of Crillon is exemplary of both the need for precise geographical and historical detail. Gadagne, could litigate against Crillon specifically 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 an uneasy 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 the late fourteenth century. As a result the authority of the Estates in Avignon was unclear. Although, the Estates and other organizations had approved the canal they had not specifically granted rights of way in the *Comtat.* Thus the validity of rights of eminent domain of the Duke of Crillon was subject to dispute and formed an open avenue for rent-seekers to attack the project.

The history of the canal of Boisgelin will be our fifth and final example of the costs of the

division of authority. The canal of Boisgelin was a large-scale project that was built in the Comtė under the financial authority of the *Assemblėe du Pays* after a number of other attempts had failed to secure the approval of a sufficient coalition. The proposed canal had two possible routes, one ran through the *Comtė* alone while the other crossed the *Terres Adjacentes.* While the later would have been cheaper, it involved bargaining with the *Terres Adjacentes* for rights of eminent domain. Rather than bargain with each community in the *Terres Adjacentes*, the *Assemblėe du Pays* avoided the issue but at a very high cost: the *Assemblėe* opted for the all *Comte'* route which was--from an engineering standpoint--much more expensive because it involved tunneling through about one kilometer of solid rock near the village of Orgon. Indeed, piercing the rock of Orgon allowed the developers to avoid the *Terres Adjacentes* communities of Senas and Salon, where the cheaper routes lay.[33] Once the tunnel was built, the *Assemblėe* 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.

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 constraints. Once again the division of authority led to higher institutional costs than if only a small canal had been built. In the case of the canal of Boisgelin the institutional costs were indirect. The *Assemblėe* did not pay off the veto player--the *Terres Adjacentes* communities that lay across the less expensive canal route. Rather it chose to bear the higher costs of digging a tunnel at Orgon, a task that absorbed half the yearly budget of the canal for eight years and totaled nearly 400,000 livres.

Through the examination of the histories of a few projects it has become clear that the institutional environment blocked irrigation. The obstacles had their origins in the long-term development of the institutional structures in the *Comtat* and the *Comtė*. At the basis of these institutions was a set of medieval political decisions that led to uncertain property rights and a large

numbers of veto players. In short the institutions inherited from the Middle Ages greatly raised the cost of building canals in southeastern France. One either had to pay off the veto players, as Craponne did, or one had to bear much higher construction costs as did the developers of the canal through Orgon.[34] The presence of active 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, for neither the king, the *Parlement* nor the *Assemblée* could reform the status of the *Terres Adjacentes.* The peculiar status of the *Terres Adjacentes* was indeed a privilege, something only the Revolution would change.[35] The problems of eminent domain were simply not addressed before the French Revolution, and the lack of clear-cut eminent domain rights hampered the development of irrigation. In this light it is surprising perhaps that any irrigation projects were developed before 1789.

IV. The Revolution and Irrigation

For twenty five years after 1789 there was no increase in irrigated area in Provence. Revolutionary turmoil and the Napoleonic wars suspended the development of irrigation. Yet even though the Revolution caused short-term delays in the extension of the irrigation network, it was bringing about institutional reforms that would be prerequisites for future development. This section examines the institutional changes brought about by the Revolution and their consequences: the construction of a number of new irrigation canals after 1820.

Between 1789 and 1815, no new irrigation canals were constructed, and those networks already in use were very poorly maintained.[36] The revolutionary turmoil during the years from 1789 to 1795 cast doubt on the strength of property rights and discouraged investment. Moreover, a number of other problems with the Revolutionary economy impeded further irrigation. Government induced inflation, price controls, and the war economy distorted the market. Most importantly the Revolutionary wars drained away manpower, and drove up the price of labor relative to land, a problem that grew even worse during the Napoleonic period (1795-1815). It is thus not surprising that

little was accomplished in terms of irrigation development between 1789 and 1815.

Nonetheless the Revolution and the Napoleonic era were important times for irrigation. Institutional reforms, initiated by the Revolutionary regime and continued by Napoleon, drastically cut the institutional costs of irrigation in the nineteenth century. The reforms consolidated all powers of eminent domain in the hands of the central government. The most dramatic changes associated with the Revolution was the destruction of the old organizations and institutions that had protected each area from royal reforms. In Provence, the annexation of the *Comtat*, and the abolition of the peculiar status of the *Terres Adjacentes* removed a major obstacle to the development of irrigation, and 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 veto players 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 *prefet*--was charged with making all the decisions. Thus, the government became the sole veto player for irrigation projects[37] The destruction of all other veto players freed irrigation development from the shackles of strategic behavior. As a result of these reforms, 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 syphon off part of the profits.

The national governments of the Revolution gave prefects complete authority over projects until they were built and removed the judiciary from the planing stages of irrigation, making it difficult for local groups to delay projects through litigation. Local groups could appeal a project before the prefect but they could no longer appeal an irrigation proposal in court. The approval of the

prefect was thus sufficient to guarantee the success of an irrigation project, and litigation--when it occurred--did not start until after the canal was built and the social gains were realized. The ability of individuals and groups to litigate was further limited because conflicts over technical and engineering issues could no longer be litigated. Instead technical questions were decided by French administrators and the judiciary's potential interventions were very limited. After the Revolution not only did the central administration have the power to provide developers of irrigation with the property rights they needed, it also had the power to enforce all the contracts itself.[38]

After the end of the Napoleonic Regime in 1815, and under a variety of different governments, irrigation in southeastern France flourished. The extent of government support was considerable. The state offered 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 were paid for by the landowners whose fields were irrigated, further evidence that institutions rather than technology or profits were the cause of the earlier market failure. The overall success of irrigation in the nineteenth century is striking: in the Vaucluse three-fourths of the increase in irrigated area between 1700 and 1860 came after 1820, and in the Bouches du Rhone nearly all the increase occurred after 1820. In sum more than 12,000 hectares (or at least a third of all the land that was irrigated in 1875) received water from canals completed between 1820 and 1860.

Whether in the case of a small project such as Plan Oriental, or in the case of a large project such as the canal of Carpentras, state approval was decisive. The canal of Plan Oriental involved only a small amount of land (less than a thousand hectares) and delivered water only to fields in a few villages. The project was quickly approved by the prefect and completed in less than four years after the project was initiated. In contrast the canal of Carpentras involved very large amounts of land (more than 4,000 hectares were eventually irrigated) in many different communities, and the very size of the project required the creation of new institutions. 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 legally grouping all the canals that drew water from Durance at the site originally used by Cabedan-Neuf alone, thereby allowing an efficient sharing of this desirable site.[39] Because the promoters were able to rely on the support and authority of the national government this canal too was completed, within twenty years of its initiation.

V. Conclusion

In the early eighteenth century, uncertain property rights over water and uncertain authority over eminent domain stifled the development of irrigation. The uncertainty in property rights over water was resolved in the middle of the eighteenth century , when owners of monopoly water rights were defeated in a series of legal battles. The veto power of owners of existing canals over new projects was abolished while their rights to the water they used were affirmed. Thus the institutional costs of irrigation fell and development proceeded, but the division of authority over rights of eminent domain still 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 a project up by using their veto power. Veto players successfully used this position to extract rents from potential developers.[40]

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 developers were forced to face these transactions costs because the state proved incapable of reform. Thus the limited development of the late eighteenth century was plagued by very high costs imposed by institutions.

The nineteenth century witnessed substantial grow in irrigation in southeastern France without significant litigation and with much shorter delays than had been customary in the previous century. The revolutionary reforms lowered transaction costs in irrigation by eliminating all local veto

players. Not surprisingly between 1820 and 1865 the area irrigated in Provence more than doubled and all the water in the Durance was used.

The problems of expanding the irrigation network in eighteenth-century France suggest that the state plays a fundamental role in economic development: it chooses the institutions that control economic activity. It defines property rights and the nature of the contracts by which they can be traded. In short the state defines the law and thereby the magnitude of institutional costs. Under the Old Regime there existed no organization--not even the state--with the power to make the changes necessary for for substantial irrigation development. Not even the absolutist state could realize fundamental reforms. The French Revolution achieved just that end through the creation of a strong central state.

Appendix

Increases in Irrigated Area

Two nineteenth-century studies of irrigation in the Vaucluse and the Bouches du Rhone by J-A Barral offer good data to investigate the magnitude of the increase in total output as a result of irrigation because they afford reliable estimates of the irrigate acreage. In 1875, the total area irrigated for the region was about 57,000 hectares, or 16% of the total cultivated area.[41] In 1760, the Vaucluse had less than 12,000 hectares of irrigated land and this area had been irrigated since the late Middle Ages. By 1789, irrigated land had increased to 14,600 hectares and by 1870, to over 20,500 hectares. Nearly all these gains were achieved by drawing from the Durance. Thus the area irrigated from the Durance tripled between 1760 to 1850, going from under 4,000 hectares to 12,400 hectares.[42] The data on the Durance is reliable because in case of drought canals received their allocation of water based on the date of the water's concession. In drought year most canals were limited to a liter of water per minute per hectare, thus both date of construction and area of irrigation were carefully recorded.

To evaluate total output changes we must know the increase in area irrigated, not only for the Durance in the Vaucluse (a figure that is available), but also from other rivers, and in the Bouches du

Rhone. The increase in irrigation from other sources is not known precisely, but can be estimated and I did so under three different hypotheses. The first estimate assumes that all new irrigation came from the Durance in the Vaucluse. This scenario is unduly pessimistic--it underestimates the increases in irrigation because a number of other projects did occur. The second assumes that the Durance was the only source of increases in irrigation and that the Bouches du Rhone's increases were of the same proportion as those in the Vaucluse. This hypothesis is still conservative because most of the irrigation development in the Bouches du Rhone, except for the canal of Craponne, occurred after 1760, but it is no doubt closest to the truth. The final estimate assumes that irrigation in Provence grew at the same rate as the area irrigated from the Durance in the Vaucluse. This last estimate is optimistic because other rivers were already well used in the early eighteenth century. The other necessary data are the increases in output per hectare due to irrigation, they can be taken to be either 80% (using land price ratio estimates) or 100% (from eighteenth- and nineteenth-century sources). Table 4 below displays the output change as the change in output per hectare change times ratio of increase in irrigated area to total cultivated area.

[table 4 about here]

Interest Rates

Choosing an appropriate rate of interest for comparisons proved to be more difficult than anticipated. Rental prices for land, from the notarial data I collected, ran at 5% of the sale prices throughout the period 1702-1870. This points to a real interest rate of 5% if we ignore appreciation in the value of land. Mortgages point to the same stable rate of 5%. French interest rates in various capital markets fluctuated between 4.75 and 6.25% in the nineteenth century. In the later part of the eighteenth Govenment interest rates seem to have been between 5 and 7%. However there are no series of interest rates for the early eighteenth century except for *rentes* (personal loans) which ranged between 3 and 5%. All of this suggest that 5% was a reasonable upper bound for French interest rates before 1789 and something closer to a lower bound for nineteenth century. Choosing a 5% interest rate

for the entire period 1700-1848 will simply bias my test against the profitability of drainage projects before 1800. This can only strengthen my findings.

As an alternative, I estimated French interest rates from British data, by estimating a model on data from 1750 to 1870 when both French and British rates are available. I ran a basic difference equation model to correct for serial correlation and then used the results to predict eighteenth-century French interest rates. Although the eighteenth-century predicted rates depend strongly on the inclusion or omission of the early nineteenth century data, the predicted interest rates differ only by at most 2% in depending on the regression specification--not enough to affect the findings of this study.[43] When using an interest rate to compute cost benefit ratios I used the French rates whenever available--that is 1750 to 1790 and 1810 to 1855-- and estimated rates when I had no other alternative.

Land prices

A) Sampling and Sorting

There were at least four active notarial *études* (practices) 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 is a complete sample of both land sale and land rental contracts from one *étude* once every five years from 1700 to 1855. Up to 1720 I sampled two *études* because the first too few land contracts. The total sample contains 1781 observations.

To obtain both an irrigated and a non irrigated land price series, it was necessary to distinguish sales and rental of irrigated land. Until 1800, such sorting was relatively easy since the contracts all contained detailed information about the quality of the land. However, during the French Revolution, notaries ceased recording such information regularly. What I had to do therefore was to rely on location data to distinguish between irrigated and dry land after 1800. Such sorting by location is imperfect, making the irrigated series a downward estimate of irrigated land prices and the dry series an upward estimate of the price of dry land after 1800.

B) Constructing the Series

The land prices were estimated using a simple procedure that allowed to take into account data from both the rental contracts--that predominated in the eighteenth century--and the sales contracts--that predominated in the nineteenth century. For rental contracts the value of a transaction was computed by capitalizing the rent using the mortgage rate. For sales the value of was simply the price. For each year and for each type of land (dry or irrigated), average prices were calculated as the sum of the value of all transactions divided by the sum of the number of ares (0.024 acres) sold for each type of land. Each of the 64 estimated prices rely on at least 15 contracts.

Canal Construction Accounts

Actual cost figures were allocated, between construction, digging and land. Clearly, land and labor (skilled and unskilled) were not the only inputs of canal construction, however these inputs were the most significant, and they were the only ones for which price series could be constructed. Moreover canal construction accounts rarely itemized costs beyond excavation (*terracement*) and skilled construction (*ouvrages d'arts*). As the former was done by unskilled labor, I divided the 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. Skilled construction involved the building of bridges for roads over the canals and aqueducts for the canal over small rivers and valley, such jobs were clearly the domain of skilled masons and stone cutters. I assigned all skilled construction and administrative costs to skilled labor, an assignment that greatly simplified the rates of return calculations. The simplification is acceptable--if we assume that there were no significant changes in the demand for stone--because the primary input of skilled construction 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 labor. An estimate for the quantity of skilled labor employed was derived in the same fashion as for unskilled labor except that the wages of skilled labor were used.

The main canal of Carpentras--the largest canal in my sample--was only 7.5 meters wide, and

it occupied an area less than 17 meters across for the first quarter of its length. All the rest of the main canal was under 5 meters across, and occupied an area less than 10 meters wide, and its branches were even smaller. All of the 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. Moreover this simplifying assumption, by reducing the estimated profits, can only strengthen any finding that irrigation was indeed profitable before 1760. Although there are only four canals surveyed, they represent between 20% and 30% of the newly irrigated area.

Two further assumptions simplified the calculation of profit rates. In the first place I disregarded certain revenues accruing to canals that are difficult to estimate. I also double-counted certain costs that are already partially taken into account in the price series. Both these assumptions bias the rates of return downward and make it more difficult to show that there was a market failure in irrigation and thus strengthen my findings.

The revenues I disregarded came from accruing 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. Mill were worth above 20,000 livres in the eighteenth century or more than 5% of the cost of a small canal.[44] The size and value of mills varied greatly and the value of a mill is not a good indicator for the rent of the fall, which 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.

The costs I double-counted were 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 canal organizations assessed all land uniformly there would be no need to double count maintenance costs. Such uniformity, though, 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 they did not assess land uniformly, either over time or across parcels. Thus the land price series only reflect maintenance costs as assessed by the institutions governing canals in Cavaillon. It was 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 reflected the discounted future revenues from land and account for maintenance costs explicitly. To do this and to simplify the calculation of internal rates of return I assumed that the developers created a sinking fund to pay for the future maintenance costs. One reason for this procedure is that it greatly simplifies the calculation of internal rates of return. The double counting of maintenance costs also created a downward bias in the rate of return estimates.

[Tables 5-8] about here]

Notes

1) Eighteenth-century travelers were struck by the poverty of southeastern-French agriculture save for the few areas were irrigation was practiced. The inhabitants of the area seemed convinced that increased prosperity could only come from increased irrigation. See Baron de Villeneuve, *Encyclopédie des Bouches du Rhone.* Vol III. Marseille: Ricard 1825-29.

2) D.M.G. Sutherland, *France* 1789-1815: *Revolution and Counterrevolution*, Oxford: Oxford University Press, 1985. Michel Vovelle, *La Chute de la Monarchie.* 1787-1872. Paris: Editions du Seuil, 1972.

3) Alfred Cobban, *The Social Interpretation of the French Revolution.* Cambridge: Cambridge University Press, 1968. page 67.

4) Douglass North, *Structure and Change in Economic History.* New York: Norton, 1985, see also Philip Hoffman, "Institutions and Agriculture in Old-Regime France" *Politics and Society.* 1988.

5) Through the paper Provence will denote the present day *departements* of the Vaucluse and the Bouches du Rhone. Strictly speaking these *departements* only represent western Provence.

6) Data on land prices confirm that output doubled when land became irrigated. See Rosenthal, *The Fruits of Revolution...* pages 68-69.

7) Abandoning the fallow leads, over two years, to twice the output on the same piece of land but at the cost of twice the labor and twice the capital.

8) The canals of Saint-Julien in Cavaillon and l'Hopital in Avignon were built between 1300 and 1400.

9) A valuable contemporary source on eighteenth-century canal technology is Delalande, *Des Canaux de Navigation.* Paris: Dessaint, 1777. See also Andre Maistre, *Le Canal des Deux Mers, Canal Royal du Languedoc* 1666-1810. Toulouse: Privat, Ch. 3.

10) Jean Rigaud, *Le Canal de Crapone. Etude Historique et Juridique relative aux Concessions Complexes des arrosages Communaux d'Istre et Grans.* Aix en Provence, 1934; Roget Caillet, *Le Canal de Carpentras.* Carpentras: Imprimerie Batailler, 1925, Ch. II and III.

11) Paul Masson, *Encyclopédie des Bouches du Rhone*, Vol. 7, Paris: Honoré Champion, 1929-1930, pp. 162-167. The canal was 100 kilometers long and it was underground for over 25 kilometers. This canal ran through the most rugged part of eastern Provence to deliver water to Marseille.

12) The history of the canal de Boisgelin shows that risk was small. The canal of Boisgelin was the most ambitious canal realized prior to the Revolution. The engineer, Brun, had warned of the very large costs associated with the tunnel necessary to go through the rock of Orgon. He did not, however, doubt that the tunnel could be built. Section IV will discuss the political and institutional factors that raised costs on the canal of Boisgelin, cf. BM Méjanes, Ms. 840(853).

13) See Pierre Goubert, *L'Ancien Régime.* Paris: Armand Colin, 1973. Vol. II, Ch. 7 for an introduction to Old-Regime finance. For a deeper investigation of eighteenth-century credit, see Guy Chaussinant-Nogaret, *Les Financiers du Languedoc au XVIII* ^{ueme} *Siecle.* Paris: S.E.V.P.E.N. 1976.

14) The canal of the Midi was primarily financed by the estates of Languedoc through loans. The project was promoted by the crown, but it did not have the capital to support the construction of the

canal and its credit reputation was poor. The estates by contrast could easily borrow the money necessary to build the canal. See Robert Forster, *The Nobility of Toulouse in the Eighteenth Century: A Social and Economic Study.* Baltimore: Johns Hopkins University Press, 1960, pp. 66-74; William Beik, *Absolutism and Society in Seventeenth-Century France, State Power and Provincial Aristocracy in Languedoc.* New York: Cambridge University Press, 1985, pp.292-297; André Maistre, *Le Canal des Deux Mers*, Ch. 4.

15) See Masson, "le canal de Provence" pp. 423-425; Hubert Elie "La Spéculation sous la Régence: l'Affaire du Canal d'Avignon á la Mer," in *Provence Historique* 3 (1953). pp 112-113 and A. Reboulet, "Construction du Canal de Crillon," *Memoires de l'Académie de Vaucluse.* 1914, pp. 46-47. In the case of the canal of Crillon, 25% of the construction costs were loaned by Jews and another 25% by nobles and bourgeois. Landowners were the largest source of credit in France because they could borrow money through mortgages. Had developers been able to interest more than a small number of landowners, the credit problem would never have existed.

16) For any year the wages are identical across sources in the area. This correlation suggests a considerable labor mobility and allows me to use data from two different towns.

17) Most of the workers were employed by religious institutions that received food was paid not on a *per diem* basis, but on a monthly or yearly basis. Not knowing how many days were in a year's wages I did not use wage bills of workers who received food as part of their compensation.

18) The data also reflects partially at least 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: S.E.V.P.E.N., 1962. Baehrel's data unfortunately stop in 1789. The sources used for wages were AC Avignon, CC 550 to CC 805; AD Vaucluse, H Bompas 182-185; H Cordeliers Avignon 62-64; E Ste Marthe E 103, BM. Cecano Ms 5659; and A. Chabert, *Essais sur le Mouvement des Revenus et de l'Activite Economique en France de* 1789 *á* 1820. Paris: De Medicis, 1930, pp. 250-260.

19) In eighteenth-century France transportation costs were high, if irrigation projects delivered water to

areas that had none, goods that had to be imported at a high costs might become produced locally. These goods, such as fodder, might have commanded a very high price. At least 15% of the area of Cavaillon was irrigated before the eighteenth century. The large area irrigated suggests that most irrigation specific goods would have commanded only a competitive price.

20) The construction of the interest rates is detailed in the Appendix.21) Cabedan-Neuf irrigated 600 hectares in and around Cavaillon and was built from 1764 to 1766; Crillon irrigated 1000 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 1850's, it irrigated more than 4500 hectares.

22) the data and results are presented in detail in the Appendix.

23) Other causes of failure were the cost associated with securing firm water rights and severe revenue problems related to the fact that most of the cost 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 only on rights-of-way simplifies the argument.

24) The best reference to the political divisions of Provence is Edouard Baratier, *Histoire de la Provence.* Toulouse: Privat, 1969. The issue is treated in more detail in Masson, *Encyclopédie*, Vol. VII, and Villeneuve, *Encyclopédie*, Vol. III.

25) See Elie "La Spéculation sous la Régence l'Affaire du Canal d'Avignon a la Mer" pp 112-113 and Reboulet, "Construction du Canal de Crillon," pp.37-50.

26) See Masson, *Encyclopédie*, Vol. VII.

27) Cf. Roland Mousnier, *La Vénalité des Offices sous Henri IV et Louis XIII.* Paris: P.U.F. 1971. and Gail Bossenga, "La Revolution Francaise et les Corporations: Trois Examples Lillois," *Annales E.S.C.* 1988, pp. 405-426.

28) J.-B. Bertin and P. Audier, *Adam de Craponne et son Canal.* Paris: Champion, 1904, p. 113.

29) On the canal of Craponne, Bertin and Audier, *Adam de Craponne*; Jean Rigoud, *Le Canal de*

Craponne; Villeneuve, *Encyclopèdie*, Vol. III, pp. 698-714. Masson, *Encyclopèdie*, Vol. VII, p. 148.

30) AN H^1 1515 (March 1780).

31) *Archives de l'Association du Canal de Cabedan Neuf*, Cavaillon: Mistral 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, Merindol proved cheaper to pay off.

32)BM. Cecano, Ms. 2459.

33)Challenges to the claims of the *Terres Adjacentes* would have meant lengthy and expensive litigation. When the *Assemblèe du Pays* decided to bear the costs of tunnelling at Orgon, it may well have chosen the cheaper of the two alternatives. Villeneuve, *Encyclopèdie*, Vol. III, pp. 714-721.

34) BM. Cecano, Ms.1605, 2459, $4^0$6198; and Reboulet, "Construction du Canal de Crillon," pp. 41-44.

35) The *Terres Adjacentes* used their peculiar status to free ride on the rest of Provence for much more than irrigation. See Villeneuve, *Encyclopèdie*, Vol. II, pp. 755-761.

36) A.D. Vaucluse, S Usines et Cours d'Eau, Cavaillon and L'Isle sur Sorgues.

37) Jean Petot, *L'Administration des Ponts et Chaussèes.* Paris: Marcel Riviere, 1958. pp. 383-87; Louis Bergeron, *L'Episode Napoleonien; Aspects Interieurs.* Paris: Editions du Seuil, 1972, pp. 33; Sutherland, *France* 1789-1815 pp. 345; and AC Vaucluse, S (Usines et Cours d'Eau).

38) Fernand Ponteil, *Les Institutions de la France de* 1814 *à* 1870.Paris: P.U.F., pp. 30-34

39) René Caillet, *Le Canal de Carpentras.* pp. 75-76.

40) Veto power was widely used to extract rents from developers in Old-Regime Provence, cf Baehrel, *Une Croissance: La Basse Provence Rurale* (1650-1789). pp. 450-456; Rene Pillorget, *Les Mouvements Insurrectionels*, pp. 196-207; Maurice Alguhon, *La Vie Sociale en Provence Interieure au Lendemain de la Rèvolution.* Paris: Societé des Etudes Robespierristes, 1970 pp. 43-59.

Appendix and Table Notes Notes

41) 140,000 American acres. Total cultivated area in the Bouches du Rhone and the Vaucluse was 356,000 hectares or 880,000 American acres. Barral, *Les Irrigations dans le Vaucluse*, pp. 323-334,

idem, *Les Irrigations dans les Bouches du Rhone*, pp. 83-87, 511-512.

42) The irrigated areas for 1789, and 1760, were calculated by subtracting from the known 1870 totals, the area irrigated from canals built from 1789 to 1870, and again from those built from 1760 to 1789.

43)The interest rate data comes from S. Homer, *A History of Interest Rates.* New Brunswick: Rutgers University Press, 1977, pp. 156-157, 172, 195-196, and 222-223 for the period 1810 to 1870 and from Francois Velde and David Weir "The Financial Market and Government Debt in France, 1750-1793," paper presented at the Second International Cliometrics Meeting, Santander, 1989, for the period 1750 to 1790. Data on *rentes* is available in Emmanuel Le Roy Ladurie, *Les Paysans du Languedoc*, Paris: S.E.V.P.E.N., 1966, pp. 1024-1025.

44) AD Vaucluse, I doc. 221.

45) AD Vaucluse, S *Usines et Cours d'eau, Avignon*, canal de Crillon (1820). The series S was being classified and sorted at the time I looked through it thus no precise references can be given, however the canal of Crillon's archives in that series amounted to one box and Cavaillon's to six.

46) Sources for tables 1 and 2 are as follows. For the first estimate of the costs of Cabedan Neuf, Barral, *Les Irrigations dans le Vaucluse*, pp. 539-544. For the second estimate of the costs of Cabedan Neuf Syndicat du Canal de Cabedan-Neuf, *Archives Et Documents* 1230-1883, Cavaillon: Imprimerie Mistral, 1883 pp. 45-52. For the canal of Crillon, Reboulet, *Le Canal de Crillon* pp. 37-40; and Barral, *Les Irrigations dans le Vaucluse*, pp. 326-327. For Plan Oriental, André Martel, "Les Origines du Canal de Plan Oriental," in *Actes du Congres des Societés Savantes.* 1955, pp. 394-395; and Barral, *Les Irrigations dans le Vaucluse*, pp. 545-547. For Carpentras, Caillet, *Le Canal de Carpentras*, vol. 2, pp. 199-201; and Barral, *Les Irrigations dans le Vaucluse*, pp. 326.

47) 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 Caillet, *Le canal de Carpentras*, vol. 1, pp. 69-70.

48) Cabedan-Neuf 1 and Cabedan-Neuf 2 are the same canal but the various sources on construction accounts could not be reconcilled. Not knowing which one was more accurate I present results based on both sets of sources.

49) The interest rates in parentheses are estimated in a procedure detailed in the appendix.

Tables

Table 1: Canal Costs (in nominal terms)[46]

Canal (date of completion)	Land Irrigated In Ares	Total Construction Costs	Capitalized Maintenance Costs
Cabedan Neuf (1767)	50,000	822,300	97,200
Cabedan Neuf (1767)	27,000	172,490	97,200
Crillon (1779)	100,000	400,000	400,000
Plan Oriental (1821)	59,000	138,595	100,000
Carpentras (1857)	500,000	5,297,011	1,000,000

Table 1 Canal Cost Data

Table 2: Itemized Costs

Canal (date of completion)	Year Under Construction	Skilled Man-days per year	Unskilled Man-days per year	Land Requirements in Ares
Cabedan Neuf (1767)	2	88,815	73,053	2,700
Cabedan Neuf (1767)	2	21,410	19,824	2,700
Crillon (1779)	3	35,088	41,190	4,950
Plan Oriental (1821)	2	63,561	46,631	975
Carpentras (1857) 6[47]		-	-	-
first 3 years		61,341	224,242	9,666
last 3 years		221,852	112,403	7,329

Table 2 Canal Construction Accounts

Table 3: Average Hypothetical Internal Rates of Return in Percent per Annum

Period	1700-30	1735-55	1760-85	1790-1820	1820-55
Cabedan-Neuf 1 (1767)	113.0	32.5	77.8	11.0	63.3
Cabedan Neuf 2 (1767)[48]	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
Estimated Interest Rate	10.7	3.8	7.1	7.8	4.3

Table 3: Hypothetical canal Profits

Table 4:

Total output Change Hypothesis	Acreage change In Hectares	Acreage Change In Percent	Irrigation Output/Hectare Increase=80%	Irrigation Output/Hectare Increase=100%
Pesimistic	14,500	4.0%	3.2%	4.0%
Best	23,630	6.5%	5.2%	6.5%
Optimistic	28,850	10.8%	8.7%	10.8%

Table 4, Estimates of Output Increases due to Irrigation

Table 5: Wages and Land Prices

Date	Wages (Unfed in Francs per day)		Land Prices (in Francs per Ares)	
	Unskilled	Skilled	Dry	irrigated
1700	0.71	1.00	5.11	21.53
1705	0.76	0.89	8.14	27.30
1710	0.73	1.02	10.8	22.01
1715	0.84	1.00	8.51	28.19
1720	0.78	1.00	15.10	25.90
1725	0.80	1.17	9.39	22.97
1730	0.80	1.12	10.31	22.02
1735	0.80	1.20	15.98	24.07
1740	0.77	1.17	13.20	23.55
1745	0.88	1.25	15.38	24.77
1750	0.89	1.12	18.27	26.94
1755	0.96	1.25	18.27	26.94
1760	0.86	1.07	19.34	28.57
1765	0.87	1.12	14.10	28.67
1770	0.92	1.25	23.61	38.54
1775	1.15	1.50	20.81	30.55
1780	1.12	1.50	22.03	50.03
1785	1.17	1.50	16.04	43.28
1790	1.28	1.50	27.56	32.71
1795	.	.	43.65	63.09
1800	2.12	2.25	19.10	29.63
1805	2.25	3.03	20.44	54.38
1810	1.81	2.45	26.98	40.97
1815	.	.	26.40	38.31
1820	1.51	2.03	24.20	36.77
1825	1.54	2.08	29.85	51.00
1830	1.51	2.03	25.90	44.11
1835	1.57	2.12	24.50	44.69
1840	1.67	2.25	23.99	51.49
1845	1.87	3.16	26.21	51.92
1850	1.92	3.00	26.79	54.00
1855	2.00	2.70	29.00	54.70

Table 6 Benefit Costs Ratios
Mortage Rate

Year	Plan Oriental	Cabedan 1	Cabedan 2	Crillon	Carpentras
1700	3.65	3.44	2.88	2.25	2.96
1705	4.40	3.96	3.24	2.62	3.38
1710	2.36	2.13	1.72	1.42	1.82
1715	4.08	3.69	3.03	2.43	3.15
1720	2.24	1.95	1.54	1.31	1.66
1725	2.57	2.37	1.95	1.57	2.03
1730	2.27	2.07	1.69	1.37	1.77
1735	1.48	1.32	1.05	0.89	1.12
1740	1.96	1.77	1.42	1.18	1.51
1745	1.62	1.45	1.16	0.97	1.29
1750	1.58	1.36	1.07	0.92	1.15
1755	1.44	1.26	1.00	0.85	1.07
1760	1.74	1.48	1.15	1.01	1.26
1765	2.72	2.41	1.93	1.61	2.05
1770	2.48	2.11	1.63	1.44	1.79
1775	1.35	1.19	0.95	0.80	1.01
1780	3.93	3.44	2.72	2.32	2.92
1785	3.82	3.43	2.77	2.28	2.92
1790	0.68	0.57	0.45	0.39	0.49
1795	-	-	-	-	-
1800	0.92	0.83	0.68	0.55	0.71
1805	2.43	2.26	1.87	1.48	1.94
1810	1.22	1.10	0.89	0.73	0.94
1815	-	-	.	-	-
1820	1.31	1.17	0.94	0.79	1.00
1825	2.14	1.88	1.49	1.27	1.60
1830	1.90	1.69	1.35	1.13	1.43
1835	2.03	1.81	1.46	1.21	1.55
1840	2.62	2.36	1.91	1.57	2.01
1845	1.88	1.76	1.44	1.16	1.51
1850	2.05	1.89	1.54	1.25	1.62
1855	2.04	1.84	1.48	1.22	1.56

Table 7 Benefit Costs Ratios
Interest Rate

Year	Plan Oriental	Cabedan 1	Cabedan 2	Crillon	Carpentras
1700	-	-	-	-	-
1705	-	-	-	-	-
1710	2.34	2.02	2.01	1.34	1.63
1715	4.01	3.64	3.74	2.39	3.05
1720	2.22	1.93	1.85	1.30	1.62
1725	2.59	2.40	2.45	1.58	2.06
1730	2.28	2.09	2.11	1.38	1.79
1735	1.49	1.33	1.28	0.89	1.13
1740	1.98	1.79	1.76	1.19	1.53
1745	1.63	1.47	1.46	0.97	1.24
1750	1.59	1.38	1.31	0.93	1.17
1755	1.46	1.27	1.23	0.86	1.09
1760	1.79	1.48	1.39	1.01	1.25
1765	2.73	2.42	2.38	1.62	2.06
1770	2.48	2.11	1.96	1.44	1.79
1775	1.36	1.19	1.16	0.80	1.02
1780	3.87	3.38	3.25	2.28	2.83
1785	3.77	3.38	3.38	2.24	2.84
1790	0.69	0.57	0.54	0.39	0.48
1795	-	-	-	-	-
1800	0.90	0.80	0.82	0.51	0.64
1805	2.34	2.18	2.26	1.42	1.79
1810	1.21	1.09	1.08	0.72	0.92
1815	-	-	-	-	-
1820	1.30	1.16	1.14	0.77	0.97
1825	2.15	1.89	1.82	1.27	1.61
1830	1.91	1.69	1.66	1.13	1.44
1835	2.05	1.83	1.81	1.22	1.57
1840	2.64	2.38	2.38	1.58	2.04
1845	1.91	1.78	1.80	1.18	1.54
1850	2.05	1.89	1.91	1.25	1.61
1855	2.06	1.86	1.85	1.24	1.60

Table 8: Hypothetical Internal Rates of Return for Irrigation Projects
In percent per annum)

Year	Plan Oriental	Crillon	Cabedan Neuf (association)	Cabedan Neuf (Barral)	Carpentras	Estimated Interest Rate
1700	156.0	120.0	157.0	84.6	50.1	–
1705	185.0	127.0	166.0	102.0	54.1	–
1710	94.0	68.8	77.9	35.4	30.1	(9.30)[49]
1715	173.0	121.0	157.0	93.2	51.5	(6.80)
1720	86.5	58.2	61.3	27.9	25.8	(6.15)
1725	105.0	80.5	95.5	45.0	34.8	(5.31)
1730	89.4	67.6	77.3	32.4	29.2	(5.39)
1735	41.3	27.6	25.3	-3.7	10.2	(5.32)
1740	71.3	52.3	55.6	19.0	22.7	(5.22)
1745	50.9	35.8	35.5	3.2	14.4	(5.46)
1750	47.5	29.6	26.7	-0.8	11.3	5.22
1755	38.8	24.1	21.4	-6.7	8.3	5.10
1760	57.5	35.7	32.6	6.0	14.7	6.50
1765	111.0	77.6	88.5	47.1	34.4	5.50
1770	98.4	62.1	64.0	35.9	28.7	7.50
1775	32.6	19.6	17.1	-11.1	5.8	5.75
1780	164.0	106.0	127.0	85.3	48.0	6.00
1785	161.0	111.0	138.0	84.7	48.5	5.55
1790	-24.0	-44.2	-36.3	-53.4	-31.2	6.50
1795	-	-	-	-	-	-
1800	-0.97	-12.1	-6.8	-36.5	-10.8	(9.30)
1805	98.6	77.8	93.5	39.8	32.8	(8.70)
1810	23.1	13.4	12.7	-17.4	2.42	6.15
1815	-	-	-	-	-	7.40
1820	29.9	18.9	17.6	-12.5	5.38	6.70
1825	81.5	55.7	58.4	24.8	24.6	5.09
1830	67.8	47.9	49.7	15.2	20.4	5.16
1835	75.4	54.6	58.9	21.1	23.5	4.33
1840	107.0	77.3	89.3	44.7	33.9	4.58
1845	67.4	53.6	59.2	17.7	22.9	3.62
1850	77.1	59.6	66.6	24.2	25.7	3.57
1855	76.2	56.1	61.4	21.9	24.1	4.41