Ranking Transport Projects by their Socioeconomic Value or Financial Interest rate of return?

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Along the last century, the casting in the transport sector was apparently clear between private actors and the public sector. For instance, public authorities were generally in charge of financing and building new infrastructures. Nevertheless, an inflexion was observed during the nineties with a significant development of public-private partnership (PPP).

This paper deals with the new issues raised by the PPP system or, more generally, by any system in which the new infrastructure is partially financed by its users. Is there, in this case, a new economic rationality of public authorities? Particularly, is there an optimal way to rank projects?

Before proposing some answers to these questions, we briefly present a historical perspective of this new trend, showing that there is a paradox. After this, we calculate the amount of subsidies needed to transform any project into a profitable project. We then show that, when public subsidies are reduced, the priority of a given project is not adequately given by its Socio Economic Internal Rate of Return (IRRse), but by a combination of its Socio Economic Net Present Value and the amount of subsidies it needs to become profitable. We demonstrate the relevance of our criterion by optimization algorithms previously developed for physical systems.

1. A clear but paradoxical trend

The practices of involving the private sector in financing, building and operating new infrastructures are increasingly observed. Thus, for developing countries, the World Bank registered\(^1\) during the period 1990-2000, among 2500 PPP projects, 675 which were in the transport sector, representing an investment budget of 135 billions $. The OECD countries were similarly involved in new experiences such as the last tolled highways in France or some international high speed railways (Eurotunnel, Perpignan-Figueras,…). Three sets of reasons are usually given to justify this private sector involvement.

The first set of reasons, which are the most frequently mentioned, relate to the ability of a private operator to manage the construction and operation of the project more efficiently. This amounts to assuming that the Internal Rate of Return (IRR) of the project is not the same depending on whether it is managed by an administration or public body or by a company which in theory keeps abreast of the progress in optimization techniques which is taking place all the time. This difference is explained in many ways: the private sector pays some categories of staff less well, is more flexible, offers faster construction times which speed up the return on investment and is also more able to resist political demands which generate additional costs.

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\(^1\) World Bank PPI Project Database.
The second set of justifications is particularly relevant to countries which are relatively unaccustomed to tolled infrastructure. J.A. GOMEZ-IBANEZ and J.R. MEYER [1993] have observed that people are reluctant to accept tolls in the case of state-owned infrastructure but quite willing to do so when the infrastructure is financed by a private company. Bringing in the private sector is therefore often the only way of applying the "user pays" principle.

The third set of justifications for the use of private finance relates to excessive public debt, either for the public sector operator taking on the project or the nation as a whole. In the case of the public sector operator, even if the debt associated with a project can be paid back by future revenue, the operator's additional debts can have adverse impacts on its rating on the financial markets. More generally, the national government may wish to limit public debt. For example, the countries in the European Economic and Monetary Union have been obliged to meet a public debt convergence criterion (a maximum of 60% of GNP). Apart from this specific case, any country with a national debt can wish to free itself from the "snowballing effect" by which debt charges increase the burden of the debt whenever interest rates are higher than the nominal rate of growth.

Nevertheless, these justifications were not less relevant thirty years ago and it seems paradoxical that private company involvement in the development of major transport infrastructure is increasing at a time when the projects that remain to be constructed are considerably less profitable than those that are already in service.

In the case of tolled roads for instance, in the three main countries concerned in Europe, France, Spain and Italy, there are already 28000 km into service. That means that the main corridors and the more profitable axes are operated from a long time. The situation is similar for the new high speed railways: the most profitable lines are already or will be soon in service and for the next projects the financial IRR are not sufficient for a self-financing.

The paradox of the appearance (or reappearance) of the PPP in these circumstances will be explained in the last paragraph of this paper because it deals with owing to the formalization of the need of subsidies we will propose. Beforehand, we have to recall the logic of investment for both the private operator and the public sector in order to explore the financial logic of a PPP.

2. The encounter of public and private investors

From the classical point of view of microeconomics, it is assumed that a private operator implements a project if the expected IRR covers:

- the market interest rate,
- plus a risk premium which takes account of the uncertainties that necessarily affect assessments of, for example, costs and future traffic and revenue,
- a profit margin.

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2 The risk premium may also include an additional amount to cover uncertainties about the stability of the country in question. This country spread can be very important in some developing countries.
Thus, with a market interest rate of 4 %, a risk premium of 4 % and a profit margin of 4 % too, the minimum targeted IRR will be 12 %. If the IRR of the project is any lower than this the operator will require a subsidy in order to reach 12 %.

The public authority is likewise using the IRR of the project, namely the discount rate which cancels out its Net Present Value (NPV). Nevertheless the valuation of this NPV takes into account not only the future accounting of the operation but also those of concurrent operators and, more generally earns and losses of all the concerned agents, including external effects such as the users surplus, consequences on safety or environmental effects. For this socio-economic assessment, we will use the notation IRRse for the internal rate of return.

In the tradition of public evaluation, a project is considered to be implemented when its IRRse is higher than a standard level\(^3\). This border-line can be interpreted as a collective profitability condition: for any project having a lower IRRse than this standard level it is assumed that the destroyed wealth would be higher than the created wealth\(^4\).

In the case of infrastructures exclusively financed by public subsidies (excluding any user contribution), if we consider not only one project but a program of scheduled projects, the objective function is the NPVse provided by the program. Thus, the question of the optimal ranking is solved by the decreasing order of the IRRse’s and the rhythm of their implementation depends of the available budget. In the case of a PPP, and more generally when the projects are partially financed by the users, the objective function of the public authority still being the total NPVse of the program, it is not obvious that the decreasing order of the IRRse’s provides the optimal ranking.

In this case, which is typically the case of railways infrastructures, the socio-economic efficiency of each unit of subsidy result not only of the IRRse of each project but also of its need of subsidy, which is itself depending of its IRR. Thus, we have formalize the relationship between the need for subsidies and the level of the IRR.

### 3. A fundamental relationship

In order to formalize this relationship we shall consider a standard project for which an investment \(C\) will be made for a duration \(d\), which is the number of years over which it has been assumed that expenditure will be evenly spread. The net profit made by the operation of the project once it has come into service is denoted by \(a\), and it has been assumed that this will increase by an annual amount \(b\).

This corresponds to the stylized, but nevertheless quite classical, account of costs and benefits that is set out in Figure 2. If it is assumed that the project comes into service at the date \(t = 0\), annual expenditure between the dates \(-d\) and 0 will be given by \(c = C/d\). The profit made once the project comes into service is assumed to take the form \((a+b.t)\).

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3 In the French case, this standard level (« taux d’actualisation du Plan »), is 8 % from the early eighties.
4 That means that the NPVse of the project, evaluated with the standard level of interest rate, would be negative.
The Internal Rate of Return (IRR) of the project, namely the discount rate which cancels out its Net Present Value (NPV), is therefore a function of the four parameters c, d, a and b. We must compare this IRR to the Rate of Return that an operator can reasonably expect.

In what follows we shall use the following notation:

- $\alpha$ is the discount rate used to calculate the Net Present Value (NPV),
- $\alpha_0$ is the discount rate which cancels out the NPV of the project, which is therefore its IRR,
- $\delta$ is the amount by which the subsidy increases the IRR,
- $\tau$ is the rate of subsidy, i.e. the percentage of c which is financed by subsidies.

For a discount rate $\alpha$, and the present value of cost and benefits from date $-d$ to date $T$, the Net Present Value is given by the following expression:

$$\text{NPV} = \int_{-d}^{T} -c \cdot e^{\alpha t} \cdot dt + \int_{0}^{T} (a + b \cdot t) \cdot e^{-\alpha t} \cdot dt$$  \hspace{1cm} (1)$$

In order to simplify the calculations that follow, we shall assume that the present value calculation has been extended to infinity, which will have little effect on the results because of the small influence of the distant future (and the known convergence of these integral functions). Equation (1) therefore becomes:

$$\text{NPV} = \left[ \frac{c}{\alpha} e^{-\alpha d} \right]_{d}^{0} + \left[ \frac{a}{\alpha} e^{-\alpha d} \right]^{\infty}_{0} + \left[ \frac{-b \cdot t}{\alpha} e^{-\alpha d} \right]^{\infty}_{0} + \left[ \frac{b}{\alpha^2} e^{-\alpha d} \right]^{\infty}_{0}$$  \hspace{1cm} (2)$$

or alternatively:

$$\text{NPV} = \frac{1}{\alpha} \left[ c(1 - e^{\alpha d}) + a + \frac{b}{\alpha} \right]$$  \hspace{1cm} (3)$$

The IRR of the project, $\alpha_0$, is therefore given by:
A rate of subsidy \( \tau \) lowers the annual cost of construction \( c \) to \( c(1-\tau) \) and raises the IRR \( \alpha_\tau \) to \((\alpha_\tau + \delta)\) such that equation (4) becomes (4')

\[
(1-\tau)c(1-e^{(\alpha_\tau+\delta)d})+a + \frac{b}{\alpha_\tau+\delta} = 0
\]

Which allows us to express the required rate of subsidy:

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\tau = 1 - \frac{a(\alpha_\tau + \delta) + b}{c(\alpha_\tau + \delta)(e^{(\alpha_\tau+\delta)d} - 1)}
\]

Rather to analyze the properties of this function, we will use its graphic representation which shows clearly some economic consequences of these properties.

4. Concavity and tyranny of the financial profitability

What is of prime importance to us in this function is clearly the relationship between \( \tau \) et \( \delta \). However, equation (5) also shows that this relationship obviously depends on the values of the parameters \( c, d, a, \) and, of course, \( \alpha_\tau \), which characterize the economics of the project and which are moreover linked together by equation (4) which established the IRR of the project \( \alpha_\tau \). If we wish to represent equation 5 we therefore need to keep some of these 5 parameters constant and vary just those whose role we wish to demonstrate. This is the well-known nomogram technique.

In this paper we shall only reproduce one of these nomograms, which will be sufficient to illustrate the point we wish to make (Figure 3). The values of \( c \) have been kept constant (assumed to be 100); as have those of \( d \) (5 years) and \( b \) (taken as 1). We have plotted \( \alpha_\tau \) against \( a \). The IRR of the project \( \alpha_\tau \) thus takes on a series of values between 2% and 14 % with a step equal to 0.4%. The function (5) which links the rate of subsidy to \( \delta \) is then shown for each of these values of \( \alpha_\tau \).
Of course, these functions must in no way be considered as completely general because of the hypotheses which were made in order to develop them and which, in particular, relate to the time series of the costs and benefits of the project in question. For instance, it is possible (and easy) to modify equation [5] by hypothesizing of an exponential instead of a linear increase in demand. Nevertheless, none of our hypotheses are extraordinary, and the conclusions suggested by the shape of these curves can be accepted.

It is quite natural for the need for subsidy to be an increasing function of the additional IRR which the operator must receive. However, the gradient of the curve decreases in a marked manner. This concavity is a counter-intuitive result: it means that the first differences between the targeted IRR and the IRR of the operation are extremely costly, particularly in the case of projects with a low IRR. For example, in the case of a project for which $\alpha = 4\%$ the plot of the subsidy rate against $\delta$ (shown in bold on Figure 3) shows that a subsidy rate in excess of 80% is required to raise the IRR for the operator to only 8%.

This first observation suggests that the leverage effect of public finance on the rhythm of investment will be more powerful when preference is given to projects, if any exist, whose IRR is very close to the target IRR required by the operator. It suggests more generally that under a public budget constraint, the role of the financial IRR could be primordial in the determination of an optimized PPP program.

5. How to find the optimal order for a set of PPP projects?

To confirm this point, we will take the set of 17 toll highway projects for which homogeneous economical data can be obtained\(^5\). Subsidizing rates have been calculated from equations (4) and (5), taking 8% as the target IRR. We assume that there exists a budget constraint the first year (F, in MEuros), this constraint increasing by 2,5 % yearly. To make clear the role of the budget constraint, we have changed its value between 1 and 1000 MEuro. For a

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\(^5\) These 17 French projects were in competition in the early 90s. Most of them have been carried out with a small contribution from public money owing to the former French financing system of tolled highways (before the European reform).
given order of the projects, the value of $F$ determines the rhythm of completion of projects, since each project needs to draw on this budget an amount $\tau.e$ of public subsidies each year.

We first examine the interest of using the IRRse as a ranking criterion. For this, we calculate the NPVse returned by three different programs obtained by ranking the projects by alphabetical or inverse alphabetical order (simulating a random combination of the projects) or by decreasing IRRse. Figure 3 shows that the IRRse is clearly more efficient as a ranking criterion than randomness, which is not surprising.

![Figure 3: Comparison of the NPVse returned by random ranking of projects or by ranking with IRRse](image)

However, our previous discussion suggests that the IRRse is probably not the best ranking criterion, mainly if budget constraints are important. Therefore, we can calculate the NPVse outputs obtained by ranking the projects with two other criteria: the IRR and the «output», defined as $O(i) = NVPse(i)/sub(i)$, where $sub(i)$ represents the amount of public subsidies required by this project to obtain the targeted IRR (8%, see §2). Figure 4 confirms our intuition: the pure financial IRR is a best ranking criterion than the IRRse, and this is the truer the tighter the budget constraint. When this constraint is lower than some value (close to one third of the average subsidy needed for a project), the NPVse output of the program obtained with the IRRse ranking is frankly disastrous when compared with the pure IRR order.
Figure 4: Comparison of the total NV/Pse returned by the 17 highway projects for different rankings, as a function of the mean subsidy required by all the projects ($<F> = 472$). We plot the % of gain obtained by choosing the specified ranking criterion compared to the total NV/Pse returned by using the IRR se as the ranking criterion.

Figure 4 also shows that our “output” criterion is even better than the IRR, for all the values of the public budget constraint. The point now is: can we find a better criterion? Can we be sure to have found the best possible ranking? The problem is that, since a program is a discrete combination of all the single projects, we cannot use the standard analytical optimization techniques such as Lagrangian multipliers or functional derivatives to find rigorously the best criterion. Therefore, we are left with exploring the different combinations of projects to find the one that yields the highest NPV se. However, the number of possible orders ($17! = 3 \times 10^{16}$) forbids an exhaustive examination of all the possibilities. Fortunately, several tools to explore efficiently the “landscape” of different combinations have been developed by several disciplines.

Let’s present briefly the three most widely used methods. First, the “simulated annealing” (Kirkpatrick [1983], van Laarhoven [1992]) method mimics the way physical systems approach thermal equilibrium. The system is taken to a high “temperature” (introducing disorder, which allows to explore a large number of configurations), then “cooled” slowly, hoping that the internal dynamics of the system will steer it towards the optimum configuration, as happens with crystallization of materials. Second, “genetic” algorithms (Mitchell [1996]) draw inspiration from natural selection, where the convergence to the optimum is obtained by random generation of individuals (each configuration), their reproduction (for example, a linear interpolation) and their selection following the desired criteria. Finally, several algorithms were recently proposed mimicking the behavior of ant colonies (Bonabeau [1999]) which are able to find shortest paths...
from their nest to the food sites. For our problem, which is relatively simple, we have chosen a reliable algorithm, inspired from the Monte Carlo method.

The algorithm can be summarized as follows. We start from an arbitrary initial state (random or given by the IRR order, this has no consequence on the final result, as shown in figure 5), we iterate the following process as many times as needed to converge.

1. Two randomly chosen projects, i and j, are permuted.
2. The total NVPse for this new ranking is calculated.
3. The permutation is systematically accepted if the new total NVPse is larger than the previous one. In this case, the temperature is slightly decreased and we start over (step 1).
4. However, to avoid the jamming of the system in a given configuration, we allow for a (small) probability of accepting the permutation even if it leads to a lower total NVPse, as in the simulated annealing algorithm. For this, we calculate $p=\exp((NVPse_{\text{new}} - NVPse_{\text{old}})/T)$, where $T$ is a “temperature”.
5. We throw a random number $q$ ($0 < q < 1$) and compare it with $p$. If it is lower, we authorize the permutation, otherwise, we cancel it. If the permutation is accepted, the temperature is slightly decreased. In any case, we start over, step (1).

We have tested the robustness of the algorithm by changing the initial value of the “temperature” (see figure 5). This temperature, as in the simulated annealing algorithm, is an arbitrary variable that allows more or less large fluctuations around the maximum value at any iteration of the search. If a higher value is fixed, the fluctuations are larger, because orders with lower total NVPse can be accepted, but the algorithm always converges to the same ranking. Figure 5 also shows that convergence to the same final, optimal ranking of projects is ensured for any initial state (IRR or random ranking).
Figure 4 shows the results obtained by the optimization algorithm. It confirms that the R ranking is the optimum, since it always corresponds to the value found by our algorithm. Even if this does not constitute a rigorous proof of the output criterion as the best ranking criterion, we think that OK.

This kind of algorithms will certainly show its full power to study programs of interdependent projects, namely programs where TRI of one project depends on the its rank (or even the date) of implementation.

6. The paradox of financial profitability and use of PPPS

The concavity of the curves in Figure 3 has another consequence we call the paradox of financial profitability (Bonnafous, 1999) and this paradox concerns, and even explains, the attraction of PPP experiences.

The aim, in short, is to determine the extent to which the use of a private partnership can reduce the burden on public finances compared with the use of a public enterprises whose debts are guaranteed by the State. We start out by assuming that the IRR for the project will be the same for both a public and a private operator (this assumption will be removed later on).

In order to present the problem clearly, we will not consider the full diversity of situations in which private investors could be involved, but just two stylized cases. These are characterized by the following restrictive hypotheses:

- In the “public” alternative, it is assumed that the operator in charge of the project is a non-profit company which nevertheless has to achieve a balance between the project's investment and operating costs (including financial charges) by using revenues from fares (and perhaps tolls or even shadow tolls). If the project's finances are not balanced, it is assumed that the deficit will be made up by subsidies from the public authority. The level of subsidies is agreed on the base of an *ex ante* cost-benefit analysis and is intended to guarantee a balance between future expenses and revenues.

- In the “private” alternative, as the operator in charge of the project is a private company, the mechanism is the same except that expenses must also include the operator's profit.

On the basis of the order of magnitude mentioned as an example in the paragraph 2, if the long-term rate on the financial market is 4 % and the risk premium is estimated at a similar 4 %, the public operator is assumed to commit itself if the IRR is equal to at least 8 %. Any rate below would have to be compensated by a subsidy to bring it back up to this level. For the same project, the private operator has to cover the same assumed market rate and risk premium, to which he has to add a profit margin of, say, a further 4 %. Thus, any IRR of less than 12 % will require a subsidy in order to reach this level.

Thus, the choice of a private operator would be more expensive for the public authorities. For instance, Figure 3 shows that a project with an IRR of 8 %, and which could
therefore be possible for a public-sector operator without a subsidy would need a subsidy rate of 45% to raise its IRR to 12%.

The shape of the curve, in particular its downward gradient, nevertheless has an important consequence. The larger the margin by which the targeted IRR exceeds the IRR of the project, the lower the marginal cost to the public purse of an increase in this targeted IRR: thus, in the case where the intrinsic profitability of a project is 4%, increasing the targeted IRR to 8% will require an amount contributed by public finance of 80% of the cost of the project. But an increase from 8% to 12% would require an additional subsidy of only 13%.

We therefore arrive at the following surprising paradox: the additional cost for public authorities who use a private operator is less for projects whose intrinsic profitability is lower.

Thus, as long as the difference between the efficiency of the two types of operator is negligible, we can conclude that the use of a player from the public sector is justified for projects whose financial profitability is moderate, while the use of a private sector player may have benefits which will not be drastically reduced by higher subsides for projects with low financial profitability. This finding ties up with the observation, which is also paradoxical, that private company involvement in the development of major transport infrastructure is increasing at a time when the projects that remain to be constructed are considerably less profitable than those that are already in service. The theoretical paradox does not, of course, fully explain the empirical paradox, as each experience of privatizing public facilities takes place within a specific historical context. There is obviously a difference between the historical context of major sub-Saharan railway lines in Africa and that of the future high speed railway crossing Alps.

Of course, we also need to consider one of the main aspects of the public–private partnership problem that we have avoided and which is the relative efficiency of public and private companies. Without claiming to investigate this issue in depth, for reasons which will be made clear below, Figure 3 shows some important consequences of the concavity when assuming that the private sector is more efficient than the public one.

Let’s imagine how a private operator could reach a higher internal rate of return for an operation either through better control of operating costs (by improving a and b in Equation 4 which determines the IRR $\alpha_0$), or by reducing capital costs (reducing c), or through shorter construction times (reducing d) or by a combination of these profitability factors. To give a simple illustration, we shall assume that a private operator improves the initial IRR $\alpha_0$ by 2%.

As we vary the value of the IRR $\alpha_0$, we obtain the subsidy rates that are shown on Figure 6 below, with the hypothesis described in section 3, namely that the “target IRR” is 8% for a public sector operator and 12% for a private sector operator.

We have therefore used a set of parameters which is more specific still than the one which provides the basis for the nomogram in Figure 3. We have done this by setting thresholds for the target IRR, thereby formalizing, in an admittedly crude manner, the effect of efficiency. Nevertheless, the plots are merely the outcome of the concave nature of the subsidy rate function.
This graph shows, for the set of parameters in question, that we can identify three distinct zones of IRR values. These relate to three fairly well-contrasted choice situations:

1) On the right hand side of the graph, where the rates of return are of the same order or higher than those targeted by public sector operators, the public sector finance will loose some money if it uses a private sector operator. When the loss is limited, such use may nevertheless be justified on the grounds of the overall increase in productivity that affects the economy as a whole because of the difference in efficiency.

2) On the left hand side of the graph, where rates of return are very low, the effect of the difference in efficiency is considerable, but we are not far away from the situation in which the scheme may have an insufficient social return, casting doubt on the project's validity. In the case of motorways, for example, it may be wiser to abandon the idea of constructing a toll motorway in favor of a four-lane dual carriage way which has less demanding and less expensive characteristics (if only because it is possible to use some or all of the existing route). However, if its construction is justified on the grounds of socioeconomic profitability, letting a private operator run it will be less costly for the public purse.

3) There is a point of transition between these zones at a certain value of $\alpha_\varepsilon$ below which the use of a private sector operator reduces public expenditure (for the reader’s information this point is located at an $\alpha_\varepsilon$ value of 5.2% for the case we have simulated). In this case the criterion of social return and that of saving public funds both dictate that a private sector operator is the best choice for society.

We must make it plain that the existence of this transition is not an inevitable consequence of the concavity of the need for subsidy function: there are obviously some values for the parameters for which the function is higher at all points for a private sector operator. The paradox of financial profitability only means that there is a point of transition for a subset of the possible values of a, b, c and d, but also of the target IRR of the two types of operator and, of course, of the difference in efficiency which is obviously decisive.
7. Conclusion

Let’s summarize here our three main results, which may seem paradoxical but are a direct consequence of the present financial constraints.

1) When financial constraints are tight, the social return of a program of investments is higher when projects are ranked according to their pure financial characteristics (such as IRR), instead of their pure socioeconomic characteristics. We have also found a hybrid optimum ranking criterion: the “output”, defined as the ratio of the socioeconomic NVP to the amount of subsidy it needs to become profitable.

2) If we assume that the private sector is more efficient than the public one, it is always more costly for the State to use a private company. However, surprisingly, the increase in cost is lower when the project IRR is lower.

3) If the private sector is more efficient than the public one, there exist situations in which using the private sector is more profitable for everyone, and this becomes truer as the project intrinsic profitability gets lower. This can partly explain the surprising trend observed nowadays: the private sector is being involved in low profitability projects.

We note to conclude that our optimization algorithm will certainly reveal all its power in more complex situations. For example, when the characteristics of the projects depend on the precise date of completion (because of external constraints, such as international development) or on the precise order of completion (a project IRR can depend on the fact that another project has been completed previously). In those complex situations, analytical treatments are certainly difficult to imagine, and simulation tools such as those developed in this paper may turn out to be a powerful tool.
Bibliography


See also http://iridia.ulb.ac.be/~mdorigo/ACO/ACO.html


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