ABSTRACT. The efficiency of execution of public works contracts is usually defined in terms of the capacity to complete works within the costs and the time agreed on in the contract. Therefore, it has been traditionally measured considering either costs overruns or delays. Our purpose is to consider both measures simultaneously, so as to develop a measure of overall efficiency of public works contracts execution. We compute this measure, through a benchmark procedure, using a non-parametric approach (DEA - Data Envelopment Analysis). The analysis is carried out employing a detailed data set of Italian public contracts for roads and highways, in the period 2000-2005.

INTRODUCTION

Public works worldwide are generally affected by inefficiency problems. The most widely analyzed expressions of this inefficiency are phenomena like cost overruns and delays in the execution of works. Both phenomena have a negative impact on social welfare, over and above the eventual increase in public expenditure.

The literature on public procurement includes now several studies which analyze the empirical relevance of cost overruns and delays. The analysis usually considers each problem separately and it is
based on very simple indicators: the difference between actual and estimated costs and the difference between the actual time of completion and the estimated time of completion, both measured in per cent of the estimated values. These indicators can only measure the extension of each problem for a given public work, but they are not able to provide us with an evaluation of how efficient the procurer has been in carrying out that work. The measurement of efficiency is, in fact, generally performed with respect to a benchmark, identified on the basis of a notion of efficiency and by the employment of consistent benchmarking techniques. In this paper, we try to develop a notion of efficiency in the execution of public works, based on the adherence to the financial and time obligations set out in the public work contract, and we propose the use of appropriate techniques for the application of this notion of efficiency for measurement purposes.

The paper is organized as follows. In the next Section we investigate the concept of efficiency of execution of public work contracts in terms of cost overruns and delays and discuss the methodological approach for measuring efficiency of execution, within a non-parametric framework. After that, we present the data and the methodology used in our empirical analysis, and then report the main results. Some remarks and a discussion of the policy implications conclude the study.

THE MEASUREMENT OF EFFICIENCY IN PUBLIC WORK MANAGEMENT EXECUTION

Cost Overruns and Delays in Public Work Procurement

In general, the efficient management of public works contracts can be measured alongside different aspects related to both the output of the work (e.g., the quality of the work, its capability of satisfying the objectives and the needs for which it has been carried out, etc.) and the process of the execution of the contract, which is instrumental to the realization of the output. We will focus on the latter issue.

In the execution of public works contracts two phenomena deserve attention: costs overruns and delays, since they affect the efficient execution of the contract (Guccio, Pignataro, & Rizzo, 2008) and have a potential negative impact on the social welfare generated by the realization of public works. These phenomena have been
increasingly investigated in the literature and, in this paper, we offer a very brief overview of their relevance.¹

Cost overruns are the additional costs incurred by contracting authorities above those agreed on in the contract. Guccio, Pignataro, and Rizzo (2012) outlined the several factors that have been considered as drivers of cost overruns, in the literature. First of all, when complex goods are procured, as it is the case for public works, there is an unavoidable degree of uncertainty related to events that may occur during the execution of the contract, which may cause a difference between what is planned and what is actually realized, or needs to be realized. Cost overruns, therefore, can be considered a consequence of the inadequate way of dealing with uncertainties in the planning stage, in terms, for instance, of poor initial design, which requires substantial changes in the execution stage, or of inaccuracy of costs forecasts.² Indeed, in some cases cost overruns are justified as a consequence of unforeseen contingencies.³

A second explanation provided for cost overruns refers to the concept of “optimism bias”, e.g., a subjective will to underestimate costs, when designing the project (Flyvbjerg, 2005). Such an underestimation can depend on planning fallacy, leading to the overestimation of benefits and the underestimation of costs (Lovallo & Kahneman, 2003) or can be, instead, determined by the politicians' attitude to look for short term political benefits, as arising from the possibility of increasing the number of works to be started, even if, in the medium-long term, they will be delayed or even not completed, because of financial problems.

A third relevant motivation offered for cost overruns is related to the potential opportunistic behavior of firms, aimed at exploiting contract incompleteness, to gain additional money over and above what has been agreed upon in the contract. Procurement features connected with the nature of the contract (fixed price vs. cost plus contracts) and with the contract awarding procedure (auctions vs. negotiations) may affect the strength of the firms' incentives to behave opportunistically. Procurers face a trade-off between providing ex ante incentives and avoiding ex post transaction costs due to costly renegotiation: the costs arising from fixed-price contracts, related to adaptation of projects, tend to be higher as the complexity of projects increases, since the potential for adaptation increases with complexity (Bajari & Tadelis, 2001; Estache, limi &
Ruzzier, 2009). On the other hand, in auctions, bidders may have an incentive to behave opportunistically; underbidding is a means to secure the win of the bid and, then, to exploit the opportunity of a renegotiation with incomplete contracts (Bajari, Mcmillan & Tadelis, 2009; Chong, Staropoli Yvrande-Billon, 2009; Guccio, Pignataro & Rizzo, 2009).

Delays refer to the excess time of completion of works with respect to the length agreed on in the contract. The presence of delays may imply cost overruns, when the delay is representative of problems connected with the realization of the original project, and additional works are required. However, there can be delays without cost overruns. Moreover, delays are representative of other costs that are not included in cost overruns for the contracting authorities (De Carolis & Palumbo, 2011). Bajari and Lewis (2011, p. 1174) underline the relevance of completion time for social welfare and, referring to highways construction, suggest that slow completion times may generate “significant negative externalities for commuters through increased gridlock and commuting times”.

The relevance of cost overruns and delays in the execution of all the public works carried out in Italy, in the period 2000-2005, was computed by Autorità di Vigilanza sui Contratti Pubblici di Lavori, Servizi e Forniture (AVCP, 2005), the Italian independent agency for controlling public contracts for works and services. Table 1 shows the distribution of public works, with reserve price above 150,000 euros, according to different classes of percent deviation from contracted cost and time.

<table>
<thead>
<tr>
<th>Class (%)</th>
<th>Cost overruns</th>
<th>Delays</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>%</td>
</tr>
<tr>
<td>≤ 0</td>
<td>4,516</td>
<td>29.35</td>
</tr>
<tr>
<td>&gt;0&lt;5</td>
<td>4,836</td>
<td>31.43</td>
</tr>
<tr>
<td>≥ 5&lt;10</td>
<td>2,204</td>
<td>14.32</td>
</tr>
<tr>
<td>≥ 10&lt;20</td>
<td>2,366</td>
<td>15.38</td>
</tr>
<tr>
<td>≥20</td>
<td>1,465</td>
<td>9.52</td>
</tr>
<tr>
<td>Total</td>
<td>15,387</td>
<td>100.00</td>
</tr>
</tbody>
</table>

Note: Public works above 150,000 euros.
First of all, out of 15,837 public works only 4,516 were completed without cost overruns (29.35%), whereas 3,632 did not experience any delay (23.60%). The data for Italian public works also show that the extension of deviation from contracted targets is different for cost and time. Although 24.90% of contracts have experienced cost overruns above 10.00% of the original cost, 64.66% of contracts exhibit a delay longer than 20.00% of the completion time agreed upon in the contract. Thus cost overruns are less marked than delays, a possible explanation being the constraints imposed by the regulation on the renegotiation of contracted costs while no such constraints exist for delays.

The Use of a Non-Parametric Frontier for Measuring the Efficient Management of Public Work Execution

The two phenomena outlined in the previous section provide us with a relevant starting point for defining the efficiency of execution of public works contracts. Efficiency can be related to the capacity of the procurer to complete the public work within the cost and the time agreed on in the original contract. The purpose of this section is, then, to find a suitable and meaningful way of measuring this capacity. We are aware that this definition of efficient management of contracts could be biased by inefficient behavior of procurers, at the moment of planning the time of completion and the cost of works (see above). However, as discussed in the previous section, time and costs agreed on in the contract are regarded as a reference point in the literature, to discuss inefficient behavior identified as cost overruns and time delays. What we will measure, on the basis of our definition of efficiency, surely captures at least a component of what should be considered efficient behavior in carrying out public works: in other words, it is surely efficient to hold to the cost and time agreed on in the contract, however both were determined,

The easy and straightforward way to measure the capacity to complete works within the cost and the time agreed on in the contract would be to use the simple indicators for each of the two dimensions: the delay (i.e., the difference between the actual time of completion and the contracted time of completion), measured in percent of the contracted time and cost overruns, which represent “actual costs minus estimated costs in percent of estimated costs” (Flyvbjerg, Holm & Bull, 2002). There are, however, several limitations in this approach. First, if we want to compare the
performance of different decision-makers on the basis of the two indicators so as to ascertain the nature of the differences, it is well possible that there will be decision makers that score better than others on one indicator, and worse on the other one. It would then be impossible to assess conclusively the relative capacity of different decision makers to achieve both contractual targets. Second, there may be a dimensionality issue, which cannot be treated if simple indicators are used: a 10% delay, for instance, does not reveal the same problem if referred to contracts of very different length.

Then, the best way to find a way of measuring the relative efficiency of decision-makers in the capacity of achieving both the targeted results of time and costs, as determined in the contract, is through benchmarking of their performance.

One of the natural candidate methodologies for our task is the non-parametric frontiers technique. The non-parametric frontier is a technique, generally used to estimate a production or a cost function with minimal assumptions, and it can easily handle multiple inputs/outputs situations. One of the most well-established and useful techniques for measuring efficiency in public sector activities is Data Envelopment Analysis (DEA).

The reasons for the widespread use of DEA are summarized as follows: it can handle multiple inputs and outputs without a priori assumptions for a specific functional form of production technologies; it does not require a priori a relative weighting scheme for the input and output variables; it returns a simple summary efficiency measurement for each Decision Making Unit (DMU), and it identifies the sources and levels of relative inefficiency for each DMU.

By constructing envelopment unitary isoquants corresponding to comparable DMU across different situations, DEA identifies as productive benchmarks those DMU that exhibit the lowest technical coefficients, i.e., the lowest input amount to produce one unit of output. In so doing, unlike statistical methods, which enable to estimate average performance, DEA allows for the identification of best practices and for the comparison of each DMU with the best possible performance among the peers, rather than just with the average.

Once the reference frontiers have been defined, it is possible to assess what would be the potential efficiency improvements available
to the inefficient DMU if they were to produce according to the best
technologies of their benchmark peers. From an equivalent
perspective, these simulations identify the necessary changes that
each DMU needs to undertake in order to reach the efficiency levels
of the most successful DMU. More formally DEA calculates the
efficiency frontier for a set of units (DMU), as well as the distance
from the frontier for each unit. This distance (efficiency score)
provides a measure of the radial reduction in inputs that could be
achieved for a given measure of output.7

In the next section we apply the abovementioned benchmark
procedure employing a data set of Italian public contracts for roads
and highways, awarded in the period 2000-2004 and completed by
2005.

MATERIALS AND METHODS

Data

We carry out an empirical analysis for Italy, where the public work
procurement system is often characterized by long delays and
relevant cost overruns (as shown in a previous section), which are
usually regarded as one of the reasons for the present under-
provision of infrastructures (Banca d’Italia, 2011).

For the purpose of this study, we used data for the public works
contracts in Italy retrieved from “Osservatorio per i lavori Pubblici” of
AVCP. The observation unit is given by the single public work and
several data are available on the various steps of the procedure –
project, selection of the contractor, execution and conclusion. The
employed sample refers to 3,113 interventions for roads and
highways, whose engineering estimated costs\(^8\) range from 150,000
euros to 5 million euros, awarded in the period 2000-2004 and
completed by 2005. Table 2 provides a distribution of the contracts
included in the sample, by class of reserve price.

Table 3 shows some descriptive statistics (mean and standard
deviation) for cost overruns and delays. They have been computed
according to different classes of value of the works and in relation to
the type of work, whether it is a maintenance or a new work.
### TABLE 2

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of obs.</th>
<th>Ex ante agreed cost of works (i.e., value of the winning bid) - Average amount -</th>
</tr>
</thead>
<tbody>
<tr>
<td>150,000 - 500,000</td>
<td>2,621</td>
<td>223.81 (83.89)</td>
</tr>
<tr>
<td>500,000 - 1,500,000</td>
<td>351</td>
<td>584.07 (141.46)</td>
</tr>
<tr>
<td>1,500,000 - 5,000,000</td>
<td>141</td>
<td>1,410.03 (725.91)</td>
</tr>
<tr>
<td>Total</td>
<td>3,113</td>
<td>318.15 (318.39)</td>
</tr>
</tbody>
</table>

Note: Monetary values in thousand Euros at current prices. Standard deviation in parenthesis.
Source: Our elaboration on data provided by AVCP.

### TABLE 3

<table>
<thead>
<tr>
<th>Class</th>
<th>Number of obs.</th>
<th>Cost overruns - mean value -</th>
<th>Delays - mean value -</th>
</tr>
</thead>
<tbody>
<tr>
<td>150,000 - 500,000</td>
<td>2,621</td>
<td>0.0780 (0.1312)</td>
<td>0.7764 (1.2171)</td>
</tr>
<tr>
<td>All</td>
<td>2,621</td>
<td>0.0789 (0.1349)</td>
<td>0.7415 (1.2273)</td>
</tr>
<tr>
<td>new</td>
<td>810</td>
<td>0.0759 (0.1226)</td>
<td>0.8544 (1.1909)</td>
</tr>
<tr>
<td>500,000 - 1,500,000</td>
<td>351</td>
<td>0.1003 (0.1627)</td>
<td>0.7115 (1.0504)</td>
</tr>
<tr>
<td>All</td>
<td>351</td>
<td>0.0999 (0.1532)</td>
<td>0.7180 (1.1113)</td>
</tr>
<tr>
<td>new</td>
<td>247</td>
<td>0.1011 (0.1840)</td>
<td>0.6961 (0.8939)</td>
</tr>
<tr>
<td>1,500,000 - 5,000,000</td>
<td>141</td>
<td>0.1076 (0.1597)</td>
<td>0.6939 (0.9384)</td>
</tr>
<tr>
<td>All</td>
<td>141</td>
<td>0.1141 (0.1778)</td>
<td>0.5945 (0.7353)</td>
</tr>
<tr>
<td>new</td>
<td>85</td>
<td>0.0978 (0.1284)</td>
<td>0.8448 (1.1736)</td>
</tr>
<tr>
<td>1,500,000 - 5,000,000</td>
<td>56</td>
<td>0.0818 (0.1367)</td>
<td>0.7653 (1.1881)</td>
</tr>
<tr>
<td>Total</td>
<td>3,113</td>
<td>0.0811 (0.1358)</td>
<td>0.8365 (1.3936)</td>
</tr>
<tr>
<td>new</td>
<td>970</td>
<td>0.0801 (0.1303)</td>
<td>0.8365 (1.3936)</td>
</tr>
<tr>
<td>repair</td>
<td>2,143</td>
<td>0.0811 (0.1358)</td>
<td>0.7750 (1.5105)</td>
</tr>
</tbody>
</table>

Note: Public works above 150,000 euros. Standard deviation in parenthesis.
Source: Our elaboration on data provided by AVCP.

As it can be seen from the table, there are not major differences in the mean values of costs overruns and delays between the two types of works, except for the last class, where delays are more marked for the new works than for the maintenance ones.
Methods

Our purpose is to consider both phenomena at once, so as to develop a measure of overall efficiency of public works contracts execution. As it was said before, we approach this objective by developing a measure of the relative capacity of decision-makers to achieve the cost and time targets, through the use of DEA.

The DEA methodology calculates an efficiency frontier for a set of DMUs, as well as the distance from the frontier for each unit. The distance between observed DMUs and the most efficient DMU, the efficiency score, gives a measure of the radial reduction in inputs that could be achieved for a given measure of output. As an illustration of this point, consider \( n \) DMUs to be evaluated. A DEA input-oriented efficiency score \( \theta_i \) is calculated for each DMU solving the following program, for \( i = 1, \ldots, n \), in the case of constant returns to scale (CRS):

\[
\begin{align*}
\text{Min} & \quad \theta_i \\
\text{subject to} & \quad y - x_i \geq 0 \\
& \quad \theta_i x_i - x \lambda \geq 0 \\
& \quad \lambda \geq 0
\end{align*}
\]

where \( x_i \) and \( y_i \) are respectively the input and output of the \( i \)-th DMU; \( X \) is the matrix of inputs and \( Y \) is the matrix of outputs of the sample; \( \lambda \) is a \( n \times 1 \) vector of variables.

The model [1] can be modified to account for variable returns to scale (VRS) by adding the convexity constraint: \( e \lambda = 1 \), where \( e \) is a row vector with all elements unity, which allows to distinguish between Technical Efficiency (TE) and Scale Efficiency (SE).9

In the application of DEA to our problem of measuring the efficiency of execution of public work contracts, we make use of the following production function specification: actual time of completion and actual cost are treated as inputs, and planned time of completion and agreed cost as outputs. Specification of these inputs and outputs is consistent with the literature reviewed in a previous section, on the performance in the execution of public works contracts. The results of the empirical analysis, based on this methodology, are presented and discussed in the following section.
RESULTS AND DISCUSSION

In our application of DEA, we assume input-oriented, technically efficient (TE) DEA frontier, under the constant returns to scale (CRS) hypothesis. This assumption is widely debated because it does not consider differences in the DMU dimension. However in our analysis, it is quite reasonable to assume the CRS hypothesis, given the stratification of our sample by reserve price and type of intervention. However, larger values of time and cost within a sample class might influence the achievement of relevant objectives for a DMU and, therefore, the adoption of the variable returns to scale (VRS) hypothesis might be reasonable. Then, to test the VRS hypothesis we ran a set of regressions using the efficiency scores from the CRS estimation as dependent variable, and reserve price as a proxy for public work dimension. As efficiency scores are truncated from below at one, we use the truncated regression (Simar & Wilson, 2007). Generally, the estimates were not significant, supporting the use of the CRS assumption in our analysis. Table 4 summarises the results.

### TABLE 4
Truncated Regression of the Efficiency Scores (CRS)

<table>
<thead>
<tr>
<th>Sample category</th>
<th>Constant</th>
<th>Reserve price</th>
<th># of obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>150,000 — 500,000 repair</td>
<td>93.92*** (0.61)</td>
<td>-3.4906 (2.2206)</td>
<td>1,811</td>
</tr>
<tr>
<td>new</td>
<td>93.34*** (0.82)</td>
<td>-1.1106 (2.9806)</td>
<td>810</td>
</tr>
<tr>
<td>500,000 — 1,500,000 repair</td>
<td>94.03*** (2.85)</td>
<td>-2.6006 (4.0606)</td>
<td>247</td>
</tr>
<tr>
<td>new</td>
<td>84.67*** (4.34)</td>
<td>1.2005* (6.0506)</td>
<td>104</td>
</tr>
<tr>
<td>1,500,000 — 5,000,000 repair</td>
<td>94.46*** (2.09)</td>
<td>-9.0307 (1.1206)</td>
<td>85</td>
</tr>
<tr>
<td>new</td>
<td>91.97*** (2.64)</td>
<td>5.0207 (1.45e06)</td>
<td>56</td>
</tr>
<tr>
<td>Total All</td>
<td>93.10*** (0.22)</td>
<td>-4.5107 (4.1607)</td>
<td>3,113</td>
</tr>
</tbody>
</table>

Note: Truncated estimates of the efficiency score (CRS). Standard errors are reported in parentheses, *** , ** and * denote significance at 1, 5 and 10 percent levels, respectively.

Table 5 reports our estimated results under this assumption. The table shows descriptive statistics for the technical efficiency scores, as measured with Farrell’s (1957) efficiency definition, for public works grouped by reserve price and type of intervention. The efficiency scores lie between zero and one. However, as the Farrell definition of the (in)efficiency scores is easily interpretable as the
percentage of input reduction that could be achieved for a given measure of output, in Table 5 we reported the percent value.

TABLE 5
Descriptive Statistics of Technical Efficiency Scores (CRS)

<table>
<thead>
<tr>
<th>Sample category</th>
<th># Efficient DMUs</th>
<th># Inefficient DMUs</th>
<th>Mean efficiency (%)</th>
<th>Mean inefficient DMUs (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>150,000 - 500,000 repair</td>
<td>23</td>
<td>1,788</td>
<td>93.01 (8.71)</td>
<td>92.92 (8.73)</td>
</tr>
<tr>
<td>150,000 - 500,000 new</td>
<td>15</td>
<td>795</td>
<td>93.05 (7.95)</td>
<td>92.92 (7.96)</td>
</tr>
<tr>
<td>500,000 - 1,500,000 repair</td>
<td>12</td>
<td>235</td>
<td>92.23 (8.87)</td>
<td>91.84 (8.91)</td>
</tr>
<tr>
<td>500,000 - 1,500,000 new</td>
<td>4</td>
<td>100</td>
<td>92.49 (9.38)</td>
<td>92.19 (9.44)</td>
</tr>
<tr>
<td>1,500,000 - 5,000,000 repair</td>
<td>12</td>
<td>73</td>
<td>92.96 (8.80)</td>
<td>91.80 (8.99)</td>
</tr>
<tr>
<td>1,500,000 - 5,000,000 new</td>
<td>6</td>
<td>50</td>
<td>92.79 (8.42)</td>
<td>91.93 (8.52)</td>
</tr>
<tr>
<td>Total all</td>
<td>72</td>
<td>3,041</td>
<td>92.94 (8.55)</td>
<td>92.77 (8.58)</td>
</tr>
</tbody>
</table>

Note: Standard deviation in parenthesis.
Source: Our elaboration on data provided by AVCP.

The results obtained by applying the DEA approach show that the overall efficiency in the execution of public works is on average relatively high. It needs to be underlined that the fully efficient observations, those on the DEA frontiers, are not necessarily the ones that simultaneously fulfil time and cost efficiency. Of course, it is also important to stress that the relatively high efficiency scores do not mean that public contracts for roads in Italy are overall executed in an efficient way.\(^{10}\)

Our estimation shows that on average only 72 DMUs (2.3% of the entire sample) are relatively efficient. The mean efficiency of the DMUs in the sample is about 92.94% of maximum efficiency, whereas the mean efficiency of the inefficient DMUs is around 92.8%. Thus, our results indicate that, on average, each DMU can reduce both actual time and costs proportionally by 7.2 percent, given the “target” values (that is, the time and costs agreed on in the contract).

Overall, there are small differences in the mean efficiency across the different subsamples. This result seems to show that the performance is relatively independent of the value of the reserve price and of the type of intervention. Figure 1 plots the distribution of efficiency scores for each subsample of observations and, overall, it appears to confirm this outcome.
Tables 6 and 7 show the average reduction (respectively, in percent and absolute values) of the actual time and costs that would have been necessary in the execution of those public works in the sample, which were not fully efficient, for achieving maximum efficiency in the fulfilment of the time and cost obligations set out in the contract.
### TABLE 6
Descriptive Statistics of Percent Time and Cost Reduction for Achieving Full Efficiency

<table>
<thead>
<tr>
<th>Sample category</th>
<th>Time reduction (%)</th>
<th>Cost reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td>150,000 - 500,000 Repair</td>
<td>-17.35 (19.91)</td>
<td>-7.08 (8.72)</td>
</tr>
<tr>
<td>New</td>
<td>-22.83 (22.24)</td>
<td>-7.09 (7.97)</td>
</tr>
<tr>
<td>500,000 - 1,500,000 Repair</td>
<td>-8.88 (9.73)</td>
<td>-8.17 (8.91)</td>
</tr>
<tr>
<td>New</td>
<td>-14.10 (14.14)</td>
<td>-7.82 (9.44)</td>
</tr>
<tr>
<td>1,500,000 - 5,000,000 Repair</td>
<td>-10.33 (10.63)</td>
<td>-8.20 (8.99)</td>
</tr>
<tr>
<td>New</td>
<td>-17.51 (18.24)</td>
<td>-8.08 (8.51)</td>
</tr>
<tr>
<td>Total</td>
<td>-17.85 (19.97)</td>
<td>-7.24 (8.58)</td>
</tr>
</tbody>
</table>

Note: Standard deviation in parenthesis.
Source: Our elaboration on data provided by AVCP.

### TABLE 7
Descriptive Statistics of Time and Cost Reduction for Achieving Full Efficiency (Absolute Values)

<table>
<thead>
<tr>
<th>Sample category</th>
<th>Average time value (days)</th>
<th>Average cost value (thousand euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual time</td>
<td>Target time</td>
</tr>
<tr>
<td>150,000 - 500,000 Repair</td>
<td>242.63</td>
<td>181.21</td>
</tr>
<tr>
<td>New</td>
<td>283.97</td>
<td>196.00</td>
</tr>
<tr>
<td>500,000 - 1,500,000 Repair</td>
<td>353.92</td>
<td>314.87</td>
</tr>
<tr>
<td>New</td>
<td>408.57</td>
<td>331.88</td>
</tr>
<tr>
<td>1,500,000 - 5,000,000 Repair</td>
<td>413.33</td>
<td>359.13</td>
</tr>
<tr>
<td>New</td>
<td>537.94</td>
<td>417.57</td>
</tr>
<tr>
<td>Total</td>
<td>276.45</td>
<td>208.78</td>
</tr>
<tr>
<td>Potential gain for all sample (total value)</td>
<td>840,682</td>
<td>634,899</td>
</tr>
</tbody>
</table>

Note: Monetary values in thousand Euros at current prices.
Source: Our elaboration on data provided by AVCP.

First of all, it is worth noting that these results are consistent with the statistics for cost overruns and delays shown in Table 3, as far as the relative importance of delays, with respect to cost overruns, is concerned. The percent of time reduction needed for the inefficiently executed public works for being as efficient as the ones on the frontier is larger than the same value for the costs. The size of the potential time improvements as emerging from Table 5 (about 18%)
is, however, relatively smaller than the one implicit in the average percent delay measured in Table 3, that is about 76%. The difference is due to the fact that while the latter simply measures the difference between the actual achievement and the “targets”, the DEA scores are based on a comparison with the best performers in the execution of works.

Secondly, even if the average efficiency of the execution of the works in the sample is relatively high, a better performance of the inefficient works, as good as the one of the efficient works, would have brought a significant improvement in social welfare, as measured by the total savings in time and costs reported at the end of Table 7 (more than 200,000 days and 85,000,000 euros).

CONCLUDING REMARKS

This analysis is an exploratory attempt to model and estimate the technical efficiency of public work execution using DEA. To the best of our knowledge there are no empirical estimates of the efficiency of execution of public works that take jointly into account cost overruns and time delays. In the DEA framework, the expected cost, equal to the winning bid, and the expected duration as agreed in the contract, were used as outputs, while the final cost and the actual duration of the work were considered as inputs. Of course, we are not identifying a proper production function, since our objective is to use DEA as a methodology for a weighted aggregation of the performance scores along the two dimensions (time and cost), through benchmarking among the different works.

The results show that the efficiency of execution of public works for roads and highways was relatively high in Italy, in the period 2000-2005. No significant differences exist across the different groups of works, as identified by classes of values of reserve prices and by types of work (maintenance or new works). However, the gain in efficiency, within the sample of works considered in our analysis, could bring out significant saving in public money and in time of completion.

Finally, we believe that the benchmark analysis developed in this paper provides more significant information about the efficiency of execution of public works than the analysis of the simple indicators of cost overruns and delays. While the latter simply measure the
difference between the actual achievement and the “targets”, the DEA scores are based on a comparison with the best performers in the execution of works, of a given amount of financial resources and time. In such a way, it is possible to offer a more realistic evaluation of efficiency of execution, since the benchmark is not the time and cost targets set for each work in the design stage, but the actual best behavior in terms of time completion of works of a given financial size (and vice versa). Therefore, it can be a fruitful approach for further research and policy analysis.

NOTES

1. Several works have shown their quantitative relevance. Flyvbjerg Holm and Bull (2002) reported that almost 9 out of 10 projects experienced some cost overruns in transport infrastructure in 20 developed and developing countries over the world, and Flyvbjerg (2005) estimated that the cost overrun of infrastructure caused by the delayed construction was at 4.6 percent per year. Bajari Houghton and Tadelis (2006) estimated that the economic costs of ex post adaptations account for about ten percent of the winning bid for California highway contracts. For developing countries Alexeeva, Padam and Queiroz (2008) showed that the value of a public road contract exceeds its engineering cost estimate by more than 20 percent and that the average delay in project completion reaches 10 months. Iimi (2009) estimated that, for road procurement in Africa, about 70 percent of contracts experienced some cost overruns, and adaptation cost was estimated at 93 cents per one dollar of contract adjustment.

2. Gauza (2007) provided a rational explanation for what could be regarded as underinvestment in project design. A higher investment on a more accurate initial design lowers the probability of renegotiation and of awarding the project to the most efficient firm, but it increases its rents, when competition is not perfect.

3. This is the case, for instance, when changes in regulations, affecting the execution of public works, occur after the contract is signed or when unforeseen contingencies require technical changes.
4. The renegotiation of contracts is severely constrained by Italian law. It specifies under what specific circumstances renegotiation is allowed, as well as the maximum amount that is permitted, and the authorization procedure required. When a greater renegotiation is needed, the contract is revoked and a new tender is issued. The project designer is liable for the mistakes in the project that cause major revisions and, therefore, the revocation of the contract.

5. DEA has been already employed in the literature on procurement, to assess the efficiency of suppliers (see de Boer, Labro & Morlacchi, 2001).

6. Statistical analysis allows for measuring a central tendency that identifies average performance and the performance of each unit is estimated by deviation from the central tendency.

7. See Cooper, Seiford and Tone (2007).

8. Engineering estimated costs are used as reserve price in tendering procedures.

9. For a review of the benchmarking approach that employs frontier methods see Bogetoft and Otto (2011) and Zhu (2008), which is more focused on non-parametric frontiers.

10. Furthermore, the efficiency scores showed a high variability: more than 25% of the contracts have a level of inefficiency between 10% and 60% and about the 75% of contracts has a level of inefficiency below 10%. More detail on efficiency scores estimate can be obtained by the authors upon request.

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