NPV Model for Evaluating the Economic Efficiency of Municipal Street Maintenance by Private Providers

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Abstract: Municipal street maintenance can be either performed by a local authority or by a private provider through public–private partnership (PPP) or outsourcing. The choice of either alternative requires proof of economic efficiency at the planning phase of these services. The economic model presented in this paper outlines the basis for the comprehensive probabilistic comparison of the economic efficiency of two approaches: (1) self-performance (public sector delivery) and (2) performance by a private provider (PPP delivery). Based on clear system boundaries, the net present values of the two alternatives are addressed, including possible risk costs. The results of the efficiency comparison are then evaluated using the net present value difference axiom and the net present value efficiency axiom. To ensure that the short-term effects of privatizing or outsourcing street maintenance services are not overrated and the long-term economic efficiency is maintained, the analysis must cover at least two long-term periods.

DOI: 10.1061/(ASCE)0733-9364(2009)135:8(701)

CE Database subject headings: Economic factors; Streets; Maintenance; Private sector; Partnership.

Introduction

The challenge of coping with the growing demands on public infrastructure with declining funding is forcing governments to seek new approaches to financing, planning, and building, but also to operating and maintaining their infrastructure. The fundamental principle of the public sector still builds upon the need to guarantee taxpayers "value for money" (Treasury Taskforce Private Finance 2006). Consequently, any approach to privatizing the delivery of public services must first be analyzed in terms of its economic efficiency. To this end, this paper presents a net present value (NPV) model for comparing the cost efficiency of public or private deliveries of municipal street maintenance services. The model is part of a research project undertaken by the Swiss Federal Institute of Technology ETH Zurich that was sponsored by the Swiss road authority and ten major cities. The proposed model addresses the qualitative and quantitative opportunities and risks that public decision makers face in selecting a public–private partnership (PPP) for the maintenance of municipal streets.

Previous Studies

The fundamental process of analyzing economic efficiency has been widely researched, especially in terms of investment budgeting. Hirst (2001) as well as Newnan et al. (2004) address this fundamental process by using NPV techniques or cost–benefit analysis. The most economically efficient form of service or delivery is also decided on the basis of the process of analysis and the definition and delimitation of the system under consideration. Boussabaine and Kirkham (2004) address the calculation of whole life-cycle costs in general but with no specific attention to PPP services or system boundaries. Beato and Vives (1996) outline different forms of private-sector participation in the provision of infrastructure services and identify their fiscal and efficiency issues, but they do not quantify these issues in economic terms. Zhang (2006a,b) evaluates and rates best value contributing factors for multicriteria tender evaluation. The same author focuses on the selection of a private partner but not on the general decision about whether to implement a PPP or not. An overview of the accounting principles of a PPP economical analysis as well as the value for money comparison is given by the Treasury Taskforce Private Finance (2006), Grimsey and Lewis (2002, 2005), and Heald (2003).

None of these publications considers the system-oriented boundary conditions in regard to

- Comparable start and end conditions; and
- Comparable, system-oriented content and time-related conditions.

Fastrich and Girmscheid (2007) give an introduction to this issue in an earlier publication, which forms the basis for a more detailed analysis of the system definition and delimitation. Yet no paper has developed a particular economic efficiency comparison model. This contribution aims to develop

- A probabilistic NPV-difference axiom and NPV-efficiency axiom for comparing public sector (PS) with PPP for municipal street network services; and
- Content and time system boundaries for the model

for practice and research.

Such a system-oriented NPV model adopts a holistic approach to assessing the "value for money" of the service alternatives in regard to PPP and PS.

The definition of PPP was taken from the Treasury Task Force Private Finance (2000) and the National Council for Public Pri-

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Note. This manuscript was submitted on October 9, 2007; approved on March 11, 2009; published online on July 15, 2009. Discussion period open until January 1, 2010; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 135, No. 8, August 1, 2009. ©ASCE, ISSN 0733-9364/2009/8-701–709/$25.00.

vate Partnership (2005), which used the following attributes to describe PPP:

- Fulfillment of public tasks;
- Long-term cooperation (life cycle);
- Cooperative task fulfillment with dynamic requirements development in regard to performance and controlling;
- Output-oriented long-term performance and coordination;
- Efficiency increase due to partnering; and
- Risk sharing.

Under this wider definition, PPP is not just limited to the procurement, including operation, of infrastructures, but also encompasses long-term partnering for the maintenance of infrastructure systems or complex public services.

Research Methodology

A model for evaluating public sector performance (noninvestive) and performance by a private partner in economic terms is presented for comparing the economic efficiency of two alternative forms of service delivery. The hermeneutic research paradigm with the constructivist research approach for structuring socio-technical realities such as management process or decision-making models, is applied as the scientific base of the viable probabilistic NPV economic efficiency model for decision support.

The task of municipal street maintenance was structured in subsystems with content, requirements, and time relations using Bertalanffy's system theory (1969). To evaluate and compare the economic efficiency if such services are executed by PS or by PPP over a long term, a viable economic efficiency evaluation model was deductive logically constructed for decision support.

The viable economic efficiency comparison model was conceptualized on the configured system "municipal street maintenance" with the physical boundaries, tasks, human, and nature impacts, and measures of maintenance in terms of cost. The potentials of different forms of delivery in reference to PS and PPP were stipulated in the model.

Triangulation (Yin 2002; Girmscheid 2007) will be used for the proof of validity and reliability of the model with the theoretical mathematical framework and realization tests to prove the intended input–output relations.

System Boundaries

A meaningful comparison of economic efficiency between PS and PPP delivery forms must be based on a clear definition of the system boundaries in regard to content and time of the model used. This necessitates the assumption of comparable boundary conditions. As such, both content and time system boundaries must be defined for the analysis (Fastrich and Girmscheid 2007).

The economic efficiency is compared using the economic minimum principle, i.e., a specific defined benefit needs to be achieved at minimum cost. In the case of municipal street maintenance, this benefit lies in the performance of the requisite maintenance works, and simultaneously ensuring the safe use and preservation of value of the street network on a defined quality output level.

Content Boundaries

Economic efficiency is analyzed on the basis of a NPV approach. This means discounting the income and expenditure to a reference point in time (Hirst 2001; Newnan et al. 2004). The income and expenditure incurred in the course of PS performance are compared with the expenditure (i.e., payments to the private partner and internal costs of local authority, such as wages, etc.) and income from a PPP form of delivery.

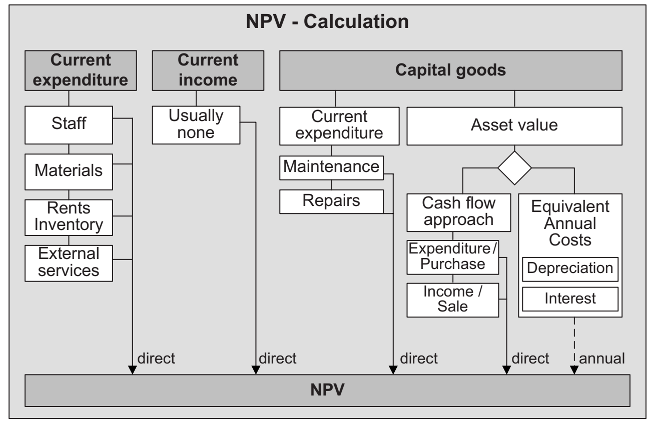

Fig. 1. NPV expenditure elements for street maintenance

Ongoing expenditure and income relating to street maintenance are incorporated directly into the calculation of the NPV. In the case of longer-term investments in capital goods, the analysis must be more differentiated (Fig. 1). In the case of street maintenance, such capital goods include, for example, the equipment and real estate needed to perform the maintenance works (machinery, building yard, administrative buildings). There are two possible fundamental approaches to including the asset values and the purchase and sale of investment goods in the model:

- Calculating the NPV by including the individual cash flows at purchase and sale of capital goods (assets); or
- Calculating the NPV by including the equivalent annual costs from the annual depreciation and interest on the invested capital for capital goods (assets).

The costs of maintaining and repairing the capital goods can be included as cash flow (expenditure) directly in the calculation of the NPV.

If the cash flow approach for the consideration of capital goods (assets) is adopted, the income and expenditure relating to the purchase and sale of capital goods over the analyzed period are included directly in the model.

If the equivalent annual costs approach for capital goods (assets) is adopted, the annual depreciation and interest on the invested capital has to be included in the model. In this case, investments in and disposals of assets only indirectly impact the annual costs through interest payments on invested capital and changed rates of depreciation.

Both methods can be applied for analyzing the economic efficiency of the two alternative forms of service delivery (PS or PPP) for performing the works in question. The cash flow approach and the equivalent annual cost approach for assets in fact produce identical results, as proved by Lücke (1955). The decision as to which method is chosen depends primarily on the structure of the data collected in the past and available in municipalities with regard to street maintenance costs and expenditure. The analysis of economic efficiency comparison based on the cash flow approach is outlined in the following. The cash flow approach captures the real payment streams and is therefore a

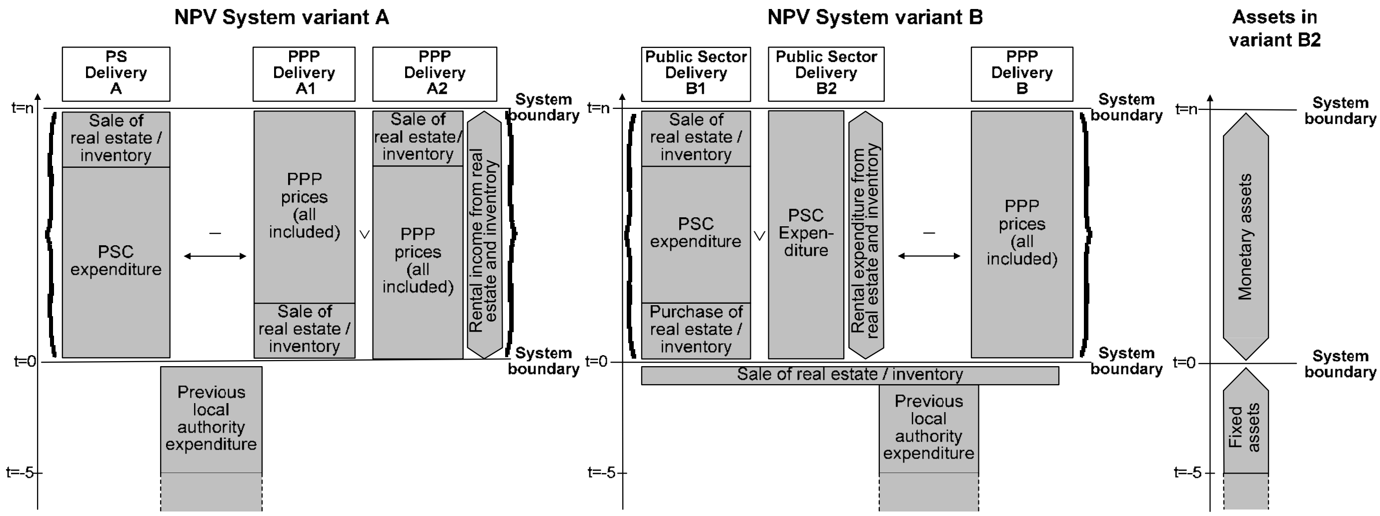

Fig. 2. NPV system variants for the cash-based NPV model for comparing economic efficiency (cash-flow oriented)

more consistent model. The equivalent annual costs were also calculated as part of the analysis. Reference is made to literature focusing on this issue (Girmscheid 2006).

Time Boundaries

As a uniform time frame must be defined for both forms of service (PPP or PS) for purposes of comparison, the contract term of a possible PPP agreement is used, which defines a start point $t=0$ and end point $t=n$. In order to ensure the comparability of the two forms of service, comparable conditions must prevail at the start and end points in time of both forms of delivery. As the calculation of NPV using the cash flow approach includes income from the sale of real estate and inventory, the results can only be compared if the same assets exist in both forms of delivery at both the start and end of the analyzed period. Two approaches are defined for the system boundaries, which both ensure clear time boundaries on the existing assets (Fig. 2).

NPV System Variant A

In the case of NPV System Variant A (Fig. 2), the comparability of PS and PPP in the economic efficiency comparison model is achieved by all already existing public sector assets being available to both forms of service at the beginning of the analyzed period, thus ensuring the same state of assets for both forms of service at this point in time. If, however, real estate or inventory assets are sold in part or whole at the start or during the course of PPP performance, there is initially no basis for comparability at the end of the term as the assets still exist in the case of PS service, but not in the case of PPP service. As such, in the case of PS service, the residual value of these assets must be included as income at the end of the analyzed period. This is crucial in order to reinstate the same state of assets at point in time $t=n$ for both forms of delivery, irrespective of whether the assets have actually been sold or not.

NPV System Variant A1 assumes that public sector assets for the PPP form of service are sold at the start of the term. System Variant A2 applies when these public sector assets are sold either at the end of or during the term, if they cannot be sold in the short term, for example. In this case, rental income from a possible lease of the assets to third parties is generated up to the time of sale in the case of PPP performance. In each of PPP Cases A1 and A2, the sale of assets has to be considered as income in the model.

NPV System Variant B

In the case of NPV System Variant B (Fig. 2), the comparability of PS and PPP in the economic efficiency comparison model for the state of assets is produced by setting the assets to zero at the start and end of the term for both forms of delivery. As such, the public sector assets are theoretically sold at a point in time $t<0$. The income from this sale is not included, as it does not occur during the analyzed period. In the case of PS performance, the assets that are still needed must either be virtually repurchased at the start of the analyzed period (B1), in which case the associated expenditure is included in the calculation of the NPV, or the cost of these assets is included as rental expenditure (B2). In the case of NPV System Variant B1, the residual value of the assets is included as income from a theoretical sale at the end of the term.

Both B1 and B2 demonstrate theoretical system boundaries. Sales do not actually take place and, as such, real estate and inventory are not actually leased (unless this was already the case). System Variant B2, in particular, does, however, offer a means of easily and practically mapping the actual payment streams, which are hard to capture, in the form of rents. These rents can either be based on amortization, interest, and maintenance costs (if these are captured in internal accounting) at internal cost rates, or standard market rental rates. In the case of this variant, the assets do not need to be further analyzed for a PPP form of delivery.

If certain assets continue to be used for PPP service, these are treated in the same way as for PS forms of service: they must either be leased or repurchased at the start of the term and reported at residual value at the end of the term.

Both NPV System Variant A and NPV System Variant B provide clear system boundaries that can be used as a basis for comparing the two forms of delivery. B2 is the most practical NPV system variant for most local authorities, as there is no need to evaluate the assets and estimate possible future sale proceeds. The real estate and inventory costs are included as rental rates. The formulas for the comparison of economic efficiency were devel-

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Table 1. Example for the Temporal Distribution of Expenses, Income, and Singular Expenses

Years t	1	2	3	4	5	6	7	...	n
Expenditure	E_1	E_2	E_3	E_4	E_5	E_6	E_7	...	E_n
Income	I_1	I_2	I_3	I_4	I_5	I_6	I_7	...	I_n
Aperiodic single cost items	/	$E^S_{\lambda_1}=E^S_2$	/	/	$E^S_{\lambda_2}=E^S_5$	/	$E^S_{\lambda_3}=E^S_7$	...	/
		$t=\lambda_1=2$			$t=\lambda_2=5$		$t=\lambda_3=7$		
		$j=1$			$j=2$		$j=3$		

oped for all NPV system variants (Girmscheid 2006). They are shown in the following on the basis of NPV System Variant B2.

NPV for Any Form of Service Delivery

The data for the economic efficiency comparison to evaluate the PS form of service are obtained from the local authorities' internal accounts. The expenditure for the PPP service alternative is forecast, on the one hand, based on the identified and assumed efficiency potential of a PS form of service (local authority expenditure) obtained from the private enterprises' bids and the transaction costs. The probabilistic cost of potential risks also needs to be estimated and added. A comparison of the economic efficiency of the two delivery forms (PS and PPP) of street maintenance service must bear in mind that costs are mainly incurred—direct income is not generated as the current political paradigm sees street maintenance as a public service. As such, only the annual cost/expenditure (negative cash flow) need to be included in the calculation of the NPV.

The comparison is based on the compilation of all cash flows (income and expenditure) for one form of service, calculated at their current value.

The following terms and values are defined:

Cash Flow. Balance of periodical expenditure (principal elements) and income (secondary elements) and aperiodical expenditure items (Table 1)

$$C_t = I_t\Big|_{t=t_a^I}^{t_e^I} - E_t\Big|_{t=1}^{n} - \{E_t^S | E_t^S = E_{\lambda_j}^S \text{ for } t=\{\lambda_j\} = (\lambda_1,\lambda_2,\ldots,\lambda_{m_3}) \vee E_t^S = 0 \text{ for } t \neq \{\lambda_j\}\}\Big|_{t=1}^{n} \quad (1)$$

Net Present Value for NPV System Variant B2. Discounted aggregate cash flow weighted to the time of incurrence relative to a point in time of analysis and decision

$$\begin{aligned}\mathrm{NPV}_{t_B} &= \sum_{t=1}^{n} \frac{C_t}{(1+q)^{(t-t_B)}} \\ &= \sum_{t=t_a^I}^{t_e^I} \frac{I_t}{(1+q)^{(t-t_B)}} - \sum_{t=1}^{n} \frac{E_t}{(1+q)^{(t-t_B)}} \\ &\quad - \sum_{t=1}^{n} \left\{ E_t^S | E_t^S = \frac{E_{\lambda_j}^S}{(1+q)^{(\lambda_j - t_B)}} \right. \\ &\quad \left. \text{for } t=\{\lambda_j\} = (\lambda_1,\lambda_2,\ldots\lambda_m) \vee E_t^S = 0 \text{ for } t \neq \{\lambda_j\} \right\}\end{aligned} \quad (2)$$

NPV of PS Delivery (Public Sector Comparator)

The compilation of all expenditure (and income, where generated) relating to public works performed by the public sector is called the "public sector comparator (PSC)." The PSC can be defined as the compilation of all expenditure (and income) relating to the public sector performance of the works discounted to a time value (Jacob 2003).

The aim of a PSC is to provide the public sector with reference values for outsourcing works, which can be used as a basis for determining their value for money, i.e., the efficiency of the form of delivery or service (Merna and Owen 1998). Expenditure can be captured either as main groups or cost types (Fig. 3).

The PSC NPV approach by main groups of expenditure in line with the structure shown in Fig. 3 is produced from the aggregate of years t in line with NPV System Variant B2 as follows (Fig. 2): Based on the cash flow at point in time $t=0$, the NPV at the reference point in time t_B of analysis is calculated by multiplying the individual values with the relevant net discount factor. The net discount factor is comprised of a cost increase index from point in time $t=0$ to point in time t and subsequently of a discount factor

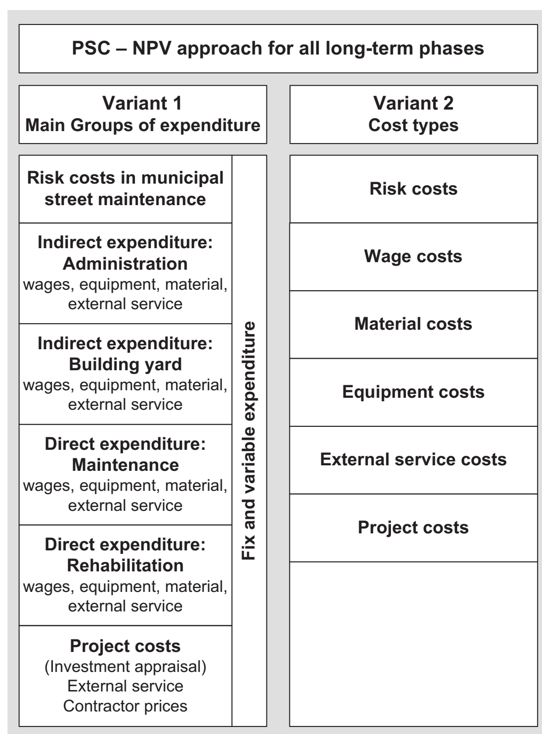

Fig. 3. Structure of expenditure for the PSC NPV—according to NPV System Variant B2

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from the point in time t to the reference point in time t_B of the analysis

$$\mathrm{NPV}_{t_B}^{\mathrm{PSC}} = \sum_{t=1}^{n} (\mathbf{C}_0^{\mathrm{PSC}^T} \cdot \mathbf{NDF}_t^{\mathrm{PSC},\mu})$$

where

$$\mathbf{C}_0^{\mathrm{PSC}} = \begin{bmatrix} E_0^{\mathrm{PSC},a} \\ R_0^{\mathrm{PSC},b} \\ P_0^{\mathrm{PSC,Proj}} \\ R_0^{\mathrm{PSC,Proj}} \\ R_0^{\mathrm{PSC},S} \end{bmatrix}, \quad \mathbf{NDF}_t^{\mathrm{PSC},\mu} = \left[\frac{(1+\boldsymbol{\mu}\mathbf{I})^t}{(1+q)^{(t-t_B)}} \right] \tag{3}$$

NPV of PPP Service Delivery

A calculation of the NPV for PPP service must include not only payments to the private partner, but also continuing and new expenditure by the local authorities. Even if a local authority opts for PPP service of municipal street maintenance, it can generally still not reduce its basic expenditure on street maintenance straight down to zero. For example, long-serving employees cannot be immediately terminated or reassigned to other departments, or it may not be possible to sell or lease buildings or inventory items immediately due to absence of demand or their continued partial use by other departments. In the case of PPP service, additional expenditure is incurred by the local authority, such as the costs of putting out to tender and awarding PPP works or the costs of monitoring and controlling the PPP service and performance during the partnership.

When analyzing the economic efficiency of a PPP service for municipal street maintenance, a dual long-term analysis is performed as follows:

- First long-term phase with establishment and routine phase; and
- Second long-term phase with extended routine phase.

In order to ensure the comparability of the two long-term phases, both periods are assumed to have the same terms. The economic efficiency for both long-term phases is anticipated and verified at the time of awarding the first long-term phase. A PPP form of service is more favorable overall only if the NPV of the first and second PPP long-term phases is better than the NPV of PS performance. The structure of expenditure in the first and second PPP long-term phases, respectively, is shown in Fig. 4.

The first PPP long-term phase is divided into an establishment and a routine phase. If a local authority/town switches its municipal street maintenance from conventional public sector performance to PPP street maintenance, the existing organizational and performance structures have to be drastically reorganized. Additional transitional costs are incurred during this time. From the second PPP long-term phase onwards, the expenditure incurred during the transitional phase for personnel adjustments, transitional rents, or financing for inventory and buildings is assumed to no longer occur.

The PPP NPV according to NPV System Variant B2 (Fig. 2) for the first and second PPP long-term phases from year $t=1$ to $t=n$ results from the structure of expenditure shown in Fig. 4 as follows:

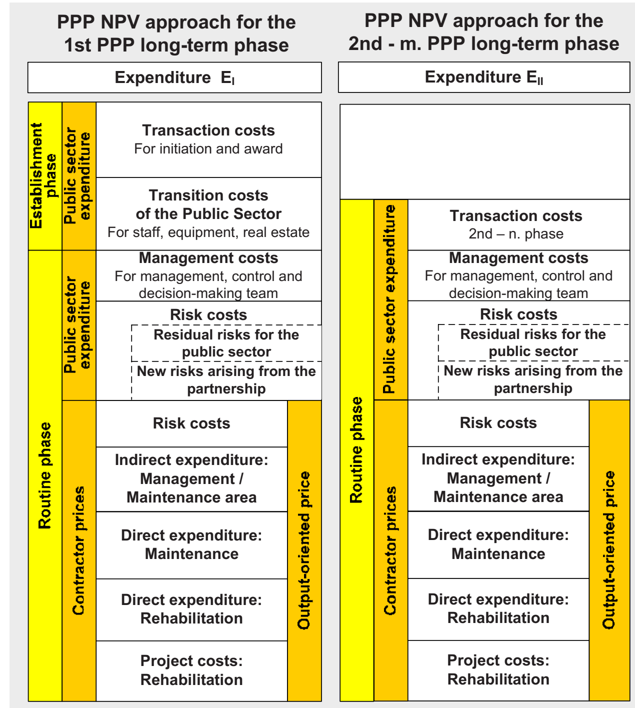

Fig. 4. Structure of expenditure of the first and second PPP long-term period for the PPP NPV according to NPV System Variant B (Fig. 2)

$$\mathrm{NPV}_{t_B}^{\mathrm{PPP,I/II}} = \sum_{t=1}^{n} (\mathbf{C}_0^{\mathrm{PPP,I/II}^T} \cdot \mathbf{NDF}_t^{\mathrm{PPP,I/II},\mu})$$

where

$$\mathbf{C}_0^{\mathrm{PPP,I/II}} = \begin{bmatrix} E_0^{\mathrm{PPP},a} \\ R_0^{\mathrm{PPP},b} \\ P_0^{\mathrm{PPP,Proj}} \\ R_0^{\mathrm{PPP,Proj}} \\ R_0^{\mathrm{PPP},S} \end{bmatrix}, \quad \mathbf{NDF}_t^{\mathrm{PPP,I/II},\mu} = \left[\frac{(1+\boldsymbol{\mu}\mathbf{I})^t}{(1+q)^{(t-t_B)}} \right] \tag{4}$$

Calculating the Risk Costs

The risk exposure of local authorities/towns in connection with PS and PPP forms of service must be separated in line with the contractual risk distribution and the additional specific risk exposure due to PPP. The local authorities will definitely have to bear some of the residual risks, but PPPs also create new risks for local authorities, such as bankruptcy of the private partner.

For calculation of risk costs, reference is made to literature focusing on this issue (Girmscheid 2006; Girmscheid and Busch 2004) and to the research project "Risk Management of PPP Municipal Street Maintenance Projects" being conducted by the Institute for Construction Engineering and Management at ETH Zurich.

Economic Efficiency Comparison Using NPV Difference and Efficiency Axioms

The following two axioms are applied to determine the economic efficiency of a PPP form of service (performance in cooperation with a private partner) compared with a PS form of service (public sector performance):

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- NPV difference axiom as a necessary condition; and
- NPV efficiency axiom as a sufficient condition.

Positive proof that the PPP form of service is more favorable than a PS form of service must be produced at all stages of initiating a PPP, i.e., during the concept and tender phase. As such, the NPV difference axiom represents the difference between the NPVs of public sector performance and PPP performance. The necessary condition is met when the NPV difference between the two forms of delivery is negative, i.e., public sector performance costs more. The NPV difference can be interpreted as savings generated by the local authority over the entire term of the PPP discounted to the current value at the reference or analysis point in time (t_B). This analysis point in time is usually the time at which the decision is made in favor of a PPP. But even if the NPV difference is positive as a necessary condition for the decision, this does not provide any information on the average percentage savings generated over the term of the PPP, relative to the reference or analysis point in time (t_B).

The NPV efficiency axiom evaluates the discounted percentage of savings of PPP service over the whole period in comparison to the NPV of PS form of service. A sufficient condition is fulfilled if the efficiency value is equal to or bigger than the benchmark to be determined by the local authority for decision making.

NPV Difference Axiom

NPV difference over the entire term relative to the analysis point in time t_B taking both long-term phases into consideration

$$\Delta \mathrm{NPV}_{t_B}^{\text{PSC-PPP}} = \mathrm{NPV}_{t_B}^{\text{PSC}} - \mathrm{Min}(\mathrm{NPV}_{t_B}^{\text{PPP,I}};\mathrm{NPV}_{t_B}^{\text{PPP,II}})$$

$$\Delta \mathrm{NPV}_{t_B}^{\text{PSC-PPP}} < 0 \quad \text{necessary condition} \tag{5}$$

NPV Efficiency Axiom

The total NPV efficiency index is the relative NPV difference over the entire term relative to the analysis point in time t_B taking both long-term phases into consideration relative to the PSC NPV

$$\mathrm{NPVE}_{t_B}^{\text{PSC-PPP}} = \frac{\Delta \mathrm{NPV}_{t_B}^{\text{PSC-PPP}}}{\mathrm{NPV}_{t_B}^{\text{PSC}}} \times 100\ (\%)$$

$$\mathrm{NPVE}_{t_B}^{\text{PSC-PPP}} = \left[1 - \frac{\mathrm{Min}(\mathrm{NPV}_{t_B}^{\text{PPP,I}};\mathrm{NPV}_{t_B}^{\text{PPP,II}})}{\mathrm{NPV}_{t_B}^{\text{PSC}}}\right] \times 100\ (\%)$$

$$\mathrm{NPVE}_{t_B}^{\text{PSC-PPP}} \geqslant x\ (\%) \ \text{sufficient condition} \tag{6}$$

Changing street maintenance from public sector to PPP performance makes economic sense if both the necessary condition (NPV difference axiom) and the sufficient condition (NPV efficiency axiom) are met.

Probabilistic Calculation of the NPV Difference

The input values for the economic efficiency comparison analysis, such as expenditure, income, risk costs, and the discount rate and cost increase indices, fluctuate within certain limits, usually around a marked expected value, due to natural or man-made influences. The deterministic approach only produces an expected value (EV), without, however, giving any indication of the bandwidth within which the results might fluctuate. But the input parameters for any prognosis of future events, like NPV analysis, already contain some uncertainties. For this reason the NPV difference can be probabilistically calculated using Monte Carlo Simulation with Latin Hypercube Sampling to deal with the uncertainties of input parameters. These methods randomly vary the individual inputs into the NPV calculation in line with density functions defined by the interval of minimum, maximum, and expected values of the individual parameters (Curran 1989). A BetaPERT density or triangular function, for example, can be used as density functions (Fig. 5). The calculation is performed using a large number of simulations, each of which determines a possible value of the NPV difference. The entire findings from the simulation runs then produce a density and distribution function which can be used to derive the bandwidth of the possible results and the likelihood of a positive or negative NPV difference (Girmscheid 2006; Girmscheid and Busch 2004).

The following applies to triangular or BetaPERT density functions of cash flow elements, cost increase indexes, and discount rates:

$$f(C^{k,c}) = \mathrm{Triangle}\{C_{\min}^{k,c}, C_{\mathrm{EV}}^{k,c}, C_{\max}^{k,c}\}$$

$$f(C^{k,c}) = \mathrm{BetaPERT}(C_{\min}^{k,c}, C_{\mathrm{EV}}^{k,c}, C_{\max}^{k,c})$$

$$f(\mu I^{k}) = \mathrm{Triangle}\{\mu I_{\min}^{k}, \mu I_{\mathrm{EV}}^{k}, \mu I_{\max}^{k}\}$$

$$f(\mu I^{k}) = \mathrm{BetaPERT}(\mu I_{\min}^{k}, \mu I_{\mathrm{EV}}^{k}, \mu I_{\max}^{k})$$

$$f(q) = \mathrm{Triangle}\{q_{\min}, q_{\mathrm{EV}}, q_{\max}\}, \quad f(q) = \mathrm{BetaPERT}(q_{\min}, q_{\mathrm{EV}}, q_{\max})$$

$$\text{where } C_{\min}^{k,c} \leqslant C_{\mathrm{EV}}^{k,c} \leqslant C_{\max}^{k,c}, \quad \mu I_{\min}^{k} \leqslant \mu I_{\mathrm{EV}}^{k} \leqslant \mu I_{\max}^{k}$$

$$q_{\min} \leqslant q_{\mathrm{EV}} \leqslant q_{\max} \tag{7}$$

The relevant distribution functions

$$F(\mathbf{C}^{k,c}, \boldsymbol{\mu}\mathbf{I}^{k}, \mathbf{q}) = \int_{\min}^{\max} f(\mathbf{C}^{k,c}, \boldsymbol{\mu}\mathbf{I}^{k}, \mathbf{q})\, d(\mathbf{C}^{k,c}, \boldsymbol{\mu}\mathbf{I}^{k}, \mathbf{q}) \tag{8}$$

The values and characteristics of the cash flow elements C, cost increase elements μI, and discount element q with distribution functions $F(C)$, $F(\mu I)$, $F(q)$ are determined by simulation run υ from the relevant inverse function $G(F(C))$, $G(F(\mu I))$, $G(F(q))$ (Girmscheid 2006; Girmscheid and Busch 2004) using random numbers Z_C, $Z_{\mu I}$, Z_q:

Cash flow from expenditure and secondary income in simulation run υ

$$C_{t,\upsilon}^{k,c} = \{C_{t,\upsilon}^{k,c} | C_{t,\upsilon}^{k,c} = G(Z_{C_{t,\upsilon}^{k,c}})$$
$$\text{where } Z_{C_{t,\upsilon}^{k,c}} = \{Z_{C_{t,\upsilon}^{k,c}} \in \mathbb{R} | (0 \leqslant Z_{C_{t,\upsilon}^{k,c}} \leqslant 1)\}\} \tag{9}$$

Cost increase index function in simulation run υ

$$\mu I_{\upsilon}^{k} = \{\mu I_{\upsilon}^{k} | \mu I_{\upsilon}^{k} = G(Z_{\mu I_{\upsilon}^{k}}) \text{ where } Z_{\mu I_{\upsilon}^{k}} = \{Z_{\mu I_{\upsilon}^{k}} \in \mathbb{R} | (0 \leqslant Z_{\mu I_{\upsilon}^{k}} \leqslant 1)\}\} \tag{10}$$

Discount function in simulation run υ

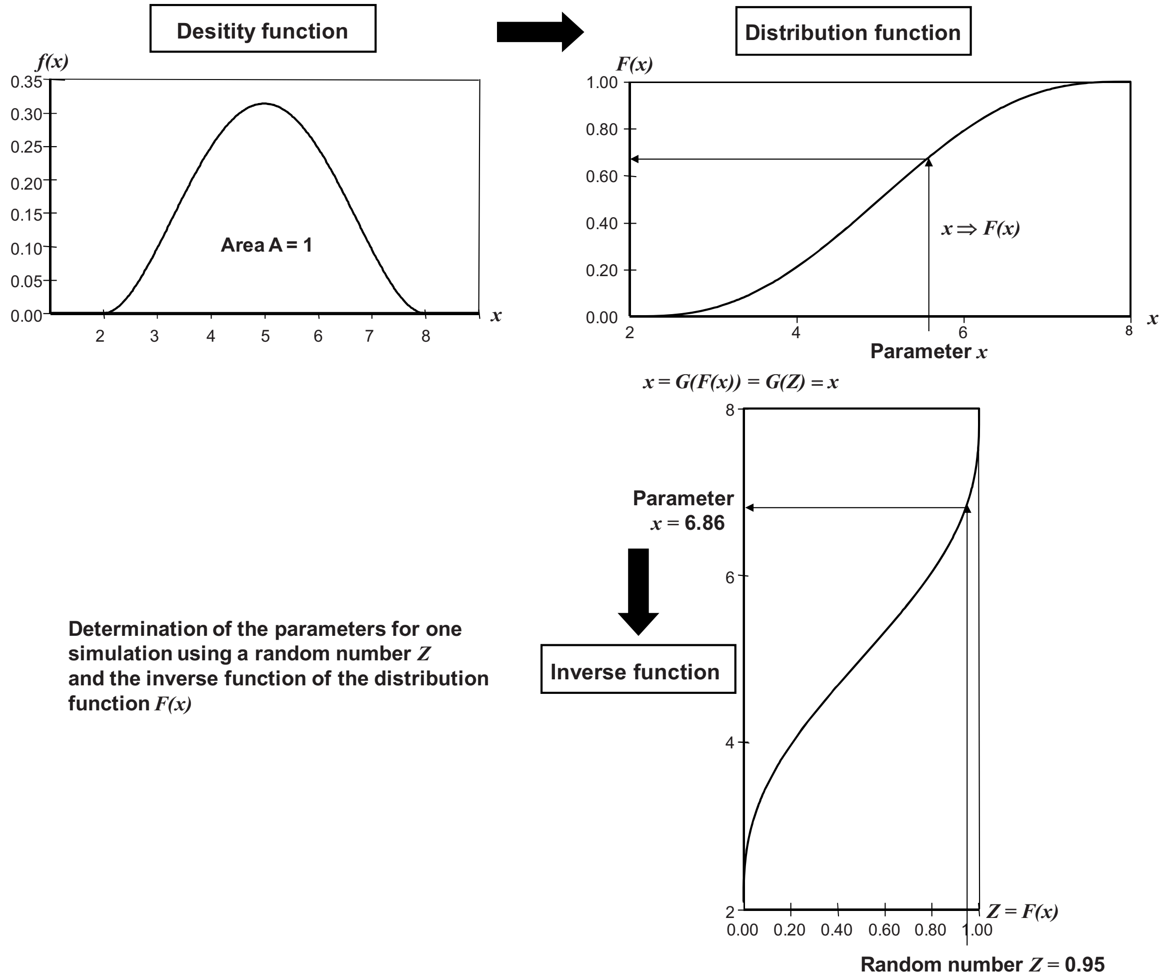

Fig. 5. Density, distribution, and inverse function of a BetaPERT distribution

$$q_\upsilon = \{q_\upsilon | q_\upsilon = G(Z_{q_\upsilon}) \text{ where } Z_{q_\upsilon} = \{Z_{q_\upsilon} \in \mathbb{R} | (0 \leq Z_{q_\upsilon} \leq 1)\}\} \tag{11}$$

NPV difference in simulation run υ

$$\Delta\mathrm{NPV}_{t_B,\upsilon}^{\text{PSC-PPP}} = \sum_{t=1}^{n} \left[\sum_c C_{0,\upsilon}^{\text{PSC},c} \cdot \frac{(1+\mu I_\upsilon^{\text{PSC}})^t}{(1+q_\upsilon)^{(t-t_B)}} - \sum_c C_{0,\upsilon}^{\text{PPP},c} \cdot \frac{(1+\mu I_\upsilon^{\text{PPP}})^t}{(1+q_\upsilon)^{(t-t_B)}} \right] \tag{12}$$

The NPV efficiency axiom can also be probabilistically determined. For simulation run υ we will receive

$$\mathrm{NPVE}_{t_B,\upsilon}^{\text{PSC-PPP}} = \sum_{t=1}^{n} \frac{\sum_c C_{0,\upsilon}^{\text{PSC},c} \cdot \frac{(1+\mu I_\upsilon^{\text{PSC}})^t}{(1+q_\upsilon)^{(t-t_B)}} - \sum_c C_{0,\upsilon}^{\text{PPP},c} \cdot \frac{(1+\mu I_\upsilon^{\text{PPP}})^t}{(1+q_\upsilon)^{(t-t_B)}}}{\sum_c C_{0,\upsilon}^{\text{PSC},c} \cdot \frac{(1+\mu I_\upsilon^{\text{PSC}})^t}{(1+q_\upsilon)^{(t-t_B)}}} \times 100[\,\%\,] \tag{13}$$

Fig. 6 is an example of the result of a probabilistic calculation of the NPV difference. In this case, the expected discounted savings from a PPP form of service are $\Delta\mathrm{NPV}^{50\%} = \$-1{,}103{,}915$ with a probabilistic occurrence of $P(W) = 50\%$. The distribution function shows that the probability of generating savings compared with the public sector performing the street maintenance is 63%.

Conclusion

The decision to opt for a PPP to perform street maintenance has far-reaching consequences for a local authority. It is difficult to reinstate any capacities once they have been downsized and to regain the lost expertise. But this should not deter local authorities from examining the possibility and, if appropriate, implementing a more economical performance of street maintenance. The responsible management of taxpayers' money necessitates a reliable forecast and calculation of the economic efficiency and the ensuing consequences prior to making the decision. The NPV difference axiom combined with the NPV efficiency axiom offers a means of comprehensively analyzing the economic efficiency of the alternative forms of delivery based on clear system boundaries. To this end, the previous expenditure on street maintenance by the local authority needs to be captured as accurately as possible, and reliable figures are needed for the costs of PPP performance. The continuing uncertainties are covered by the probabilistic approach to NPV calculation and by the risk costs to be incorporated.

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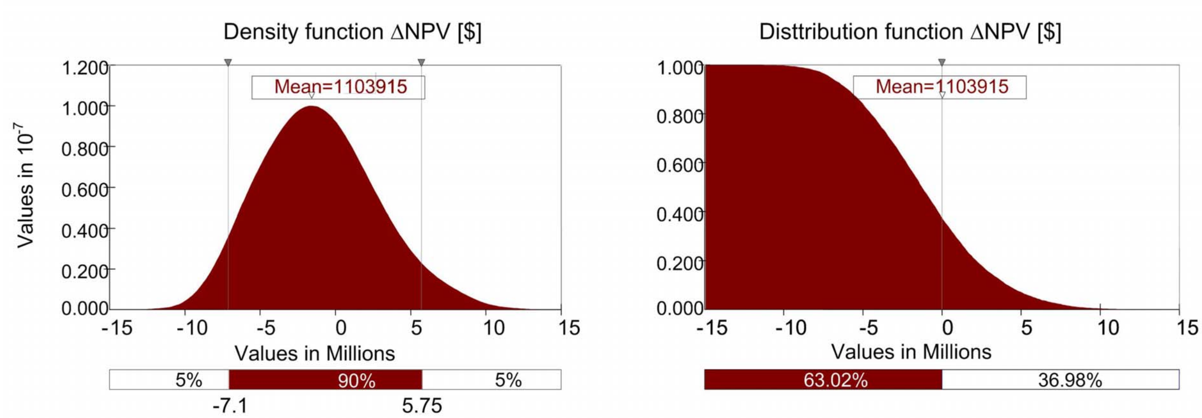

Fig. 6. Results of a probabilistic calculation of the NPV difference (savings are negative)

Notation

The following symbols are used in this paper:

$\mathbf{C}_0^{\mathrm{PPP,I/II}}$ = vector of cash flow of the first and second PPP long-term phase in year $t=0$;

$\mathbf{C}_0^{\mathrm{PSC}}$ = vector of cash flow of PS performance in year $t=0$;

$C^{k,c}$ = cash flow elements c of delivery form k;

$C_{\mathrm{EV}}^{k,c}/\mu I_{\mathrm{EV}}^{k}/q_{\mathrm{EV}}$ = expected value of $C^{k,c}/\mu I^k/q$;

$C_{\max}^{k,c}/\mu I_{\max}^{k}/q_{\max}$ = Maximum value of $C^{k,c}/\mu I^k/q$;

$C_{\min}^{k,c}/\mu I_{\min}^{k}/q_{\min}$ = minimum value of $C^{k,c}/\mu I^k/q$;

C_t = cash flow in year t;

$C_{t,\upsilon}^{k,c}$ = cash flow elements c of delivery form k in simulation run υ at point in time t;

c = cash flow elements; $c=\{$operating maintenance, structural maintenance depot, maintenance administration, $\ldots\}$;

E_t = periodic expenditure over the term $(0<t\leq n)$ in equal or different amounts;

E_t^S = aperiodic single cost items, one-off or recurring at larger or smaller intervals (aperiodically);

$E_0^{\mathrm{PSC},a}$ = expenditure a for PS performance in year $t=0$; $a=\{$administration, maintenance depot, operating maintenance, structural maintenance$\}$;

$E_0^{\mathrm{PPP},a}$ = expenditure a for PPP performance in year $t=0$ [first PPP long-term phase: $a=\{$transaction, transitional expenses, controlling, private partner payments$\}$], [second PPP long-term phase: $a=\{$transaction, controlling, private partner payments$\}$];

$F(C^{k,c},\mu I^k,q)$ = distribution function of $C^{k,c}$, μI^k, and q, respectively;

$f(C^{k,c},\mu I^k,q)$ = density function of $C^{k,c}$, μI^k, and q, respectively;

I_t = periodic income over a limited term $(t_a^I\leq t\leq t_e^I)$ in equal or different amounts (secondary elements);

j = continuous index;

k = delivery form $k=(\mathrm{PSC}\vee\mathrm{PPP})$;

m = number of aperiodic single payments $(1,2,3,\ldots,m)$;

$\mathbf{NDF}_t^{\mathrm{PPP,I/II},\mu}$ = vector of net discount factors μ ($\mu=\{$wages, production, $\ldots\}$) for year t;

$\mathbf{NDF}_t^{\mathrm{PSC},\mu}$ = vector of net discount factors μ ($\mu=\{$wages, production, $\ldots\}$) for year t;

NPV_{t_B} = net present value relative to point in time t_B;

$\mathrm{NPV}_{t_B}^{\mathrm{PPP,I}}$ = net present value of PPP delivery in the first long-term phase relative to point in time $t=t_B$;

$\mathrm{NPV}_{t_B}^{\mathrm{PPP,II}}$ = net present value of PPP delivery in the second long-term phase relative to point in time $t=t_B$;

$\mathrm{NPV}_{t_B}^{\mathrm{PPP,I,III}}$ = net present value of, respectively, the first and second long-term phase relative to point in time t_B;

$\mathrm{NPV}_{t_B}^{\mathrm{PSC}}$ = net present value of PS delivery relative to point in time $t=t_B$;

$\mathrm{NPVE}_{t_B}^{\mathrm{PSC\text{-}PPP}}$ = total NPV efficiency index of a PPP compared with PS delivery over the entire term $t=1$ to $t=n$;

n = last year of the analyzed period;

$P_0^{\mathrm{PPP,Proj}}$ = project costs of PPP performance in year $t=0$;

$P_0^{\mathrm{PSC,Proj}}$ = project costs for PS performance in year $t=0$;

q = discount rate (development of monetary value);

q_υ = discount function in simulation run υ;

$R_0^{\mathrm{PPP},b}$ = risk costs b of PPP performance in year $t=0$, $b=\{$residual risks, new risks$\}$;

$R_0^{\mathrm{PPP,Proj}}$ = project risks of PPP performance in year $t=0$;

$R_0^{\mathrm{PPP},S}$ = one-off risks of PPP performance in year $t=0$;

$R_0^{\mathrm{PSC},b}$ = risk costs b for PS performance in year $t=0$; [$b=\{$natural, man-made, operating maintenance, structural maintenance$\}$];

$R_0^{\mathrm{PSC,Proj}}$ = project risks for PS performance in year $t=0$;

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$R_0^{\mathrm{PSC},S}$ = one-off risks for PS performance in year $t=0$;
t = term index;
t_B = reference point in time for the analysis;
t_a^I = first year in which income is generated;
t_e^I = last year in which income is generated;
x = minimum efficiency index (%)—determined by the local authority;
$Z_{C_{t,\upsilon}^{k,c}}$ = random number for cash flow function $C_{t,\upsilon}^{k,c}$;
Z_{q_υ} = random number for discount function q_υ;
$Z_{\mu I_\upsilon^k}$ = random number for cost increase function μI_υ^k;
$\Delta\mathrm{NPV}_{t_B}^{\mathrm{PSC\text{-}PPP}}$ = net present value difference between PPP and PS performance relative to point in time $t=t_B$;
$\Delta\mathrm{NPV}_{t_B^\upsilon}^{\mathrm{PSC\text{-}PPP}}$ = net present value difference to point in time t_B in simulation run υ;
λ_j = year in which singular payments are incurred;
μI = cost increase index μ ($\mu=\{\text{wages}, \text{production}, \ldots\}$);
μI_υ^k = cost increase index function μ of delivery form k in simulation run υ;
$\sigma_{\mathrm{PSC\text{-}PPP}}^2$ = standard deviation of the net present value difference; and
υ = simulation run/scenario υ.

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