Received 19 April 2016
Revised 27 August 2016
28 September 2016
Accepted 2 December 2016

Using game theory to stimulate provision of local public facilities

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Abstract

Purpose – The purpose of this paper is to study how the central government can use well-known game-theoretical concepts in order to stimulate provision of local public facilities.
Design/methodology/approach – The authors use the classical adverse selection framework to discuss how the central government can use investment transfers as efficiently as possible to stimulate increased provision of local public facilities.
Findings – The benefits of local public facilities, such as kindergartens, schools, and primary healthcare institutions are greater than what each local government takes into account. Consequently, the central government, which maximizes social welfare in total, wants more local public facilities than the individual local government find optimal to supply. The central government thus would want to stimulate additional provision of local public facilities using contracts where local governments receive a transfer as compensation for increasing their supply. Since local governments differ regarding their efficiency in supplying facilities, the required amount of facilities and the corresponding transfer size should be allowed to vary across local governments.
Originality/value – Almost all countries are organized with multiple tiers of government, and local governments are important providers of many important welfare services. After labor, facilities are probably the second most important input in production of local public services. This paper offers insights into how the central government can efficiently stimulate the production of local public facilities.

Keywords Buildings, Modelling, Property management, Maintenance, Investments

Paper type Research paper

1. Introduction

Almost all countries are organized with multiple tiers of government, and local governments are accountable providers of many important welfare services. After labor, facilities are probably the second most important input in production of local public services. It is thus essential for both researchers and practitioners in the facility and property management disciplines to analyze local governments' incentives and how good management of local public facilities can be stimulated.

We study how positive externalities in the production of public services create a difference between the amount of local public facilities that the central government desires, and what each local government finds it optimal to supply. The difference arises because the central government takes the externalities of production into account, while each local government does not, at least not to full extent. As a consequence, the central government would like local governments to supply more facilities than what the local governments themselves find to be optimal.

Our model justifies central government intervention in local policies because of positive externalities, often referred to as spillover effects. Such positive externalities in the production of local public goods are widely acknowledged, see, e.g. Koide (1985) and Bloch and Zenginobuz (2006, 2007). Several examples of positive externalities can be thought of. First, local governments provide education for the young, and thus contribute to increasing the skills of the labor force. High-skilled workers typically have higher income and thus pay more taxes, which again benefits the society as a whole. In addition, a strong

Property Management
Vol. 35 No. 4, 2017
pp. 368-379

0263-7472
DOI 10.1108/PM-04-2016-0018

primary education system can be beneficial as it helps to increase social mobility and reduce crime and poverty. Second, local governments provide basic healthcare services which can save the society's large expenditures as it works to keep the population healthier with less need for hospital nights and sick leave. Hence, a healthier population implies lower overall expenditures, and thus a smaller tax burden for citizens in all local governments. Third, inhabitants in one local community frequently enjoy services provided by other local governments, e.g. when commuting to work in neighboring communities. Consequently, a local government that maximizes the utility of its own residents will provide less facilities than what is desired by a central planner who maximizes overall social welfare. This is a special case of underprovision of public goods, which is a well-known problem in economics, first properly acknowledged in the seminal work by Coase (1974). Such deficiency generally calls for central government intervention to enhance social welfare.

We study how the central government can best stimulate more provision of facilities by local governments using a transfer earmarked for facilities[1]. If the efficiency in supplying additional facilities differ between local governments, so will the optimal grant and required supply of local public facilities. Such differences can arise, e.g. due to different skills in facility management (Hopland, 2014b). However, it is not easy for a central government to measure efficiency in local governments precisely. Consequently, the central government has a disadvantage, since it knows less about the efficiency among local governments than the local governments know themselves. The game theory literature refers to this kind of asymmetrical information as adverse selection problems (see e.g. Macho-Stadler and Pèrez-Castrillo, 2001 for a comprehensive introduction). Shortly summarized, we will see that efficient local governments have incentives efficient to downplay their true efficiency in order to be subject to less demanding contracts. The challenge is thus to design a contract that makes each local government reveal its true efficiency. Akerlof (1970) is the great pioneer of this field, while more recent contributions include Laffont and Tirole (1993), Bolton and Dewatripont (2005), and Laffont and Martimort (2009).

In our model, we simplify by defining local governments as either "efficient" or "inefficient" in supplying facilities, since the basic intuition is the same as in more complex models with many efficiency levels[2]. The main reason for this approach is that we wish to focus on the intuitive story and keep the mathematical derivations at a minimum. However, there are also policy-related arguments in favor of a simple set-up. It is always a goal to limit the need for bureaucracy when constructing policy tools. The more detailed the system is in terms of offering tailored contracts to each local government, the higher the administrative costs related to designing the contracts and monitoring that the local governments fulfill them. Hence, it can be useful for the central government to group local governments into a few, in our case two, categories.

Our discussion of theoretical concepts has practical implications for policymaking, as central governments frequently pay a share of local governments' investment expenditures. An example is Norway, where the central government has stimulated local supply of facilities for elderly patients by covering a fixed share of the local government's costs. However, the framework we propose is more refined, since it further increases overall efficiency by reducing the central government's informational disadvantage.

The remainder of the paper is organized as follows: Section 2 presents an overview of the existing literature. Section 3 looks at the relationship between central and local governments in countries with several tiers of government. Section 4 discusses the results of the model, while Section 5 offers some concluding remarks.

2. Literature on public facilities

Our analysis follows a large literature on public capital spending, including Oxley and Martin (1991), De Haan *et al.* (1996), and Sturm (1998, ch. 3), among others. During the 1980s, public investment as share of gross domestic product (GDP) declined in a majority of the OECD countries, while at the same time total public spending stopped growing as share of GDP. It became a popular claim that public investment is an easy target in periods of fiscal consolidation. Roubini and Sachs (1989, pp. 108-109) argue that "in periods of restrictive fiscal policies and fiscal consolidation capital expenditures are the first to be reduced (often drastically) given that they are the least rigid component of expenditures." Hence, one should expect that public facilities are given little attention in times of fiscal turmoil, such as during the recent financial crisis.

Based on panel data for a sample of 22 OECD countries, De Haan *et al.* (1996) and Sturm (1998, ch. 3) find evidence in favor of the hypothesis that public investment is reduced as share of public spending during periods of fiscal stringency. They also find that frequent government changes lead to cuts in investment spending. Akitoby *et al.* (2006), analyzing public spending in 51 developing countries during 1970-2002, confirm the hypothesis that investments are cut disproportionately more than other expenditures during economic downturns. On the other hand, Sanz (2011) provides evidence that productive spending (spending components assumed to promote long-term growth) is isolated from budgetary cuts in OECD countries.

In the USA, the same concerns were raised regarding a possible "infrastructure crisis" in state and local governments. Hulten and Peterson (1984) document the decline in capital spending in the 1970s and early 1980s and offer possible explanations. A key issue in the debate was whether the decline was a sensible response to changing economic and demographic conditions or whether it reflected myopic behavior by state and local politicians. Proponents of the latter explanation (e.g. Inman, 1983) emphasize that capital spending is an easy target when there is a need to balance public budgets because it takes time for the adverse consequences to occur. In a series of papers, Holtz-Eakin and Rosen (1989, 1993) provide more formal tests, and they generally find that the hypothesis of rational forward-looking behavior is an adequate description of municipal capital spending[3].

Borge and Hopland (2012) argue that low maintenance expenditures and poor facilities conditions to some extent are due to myopic politicians who are unable to make long-run prioritizations, and thus favor other expenditures that are more visible to voters in the short run[4]. This argument implies that the maintenance backlog, at least to some extent, can be explained by irrational behavior from the policymakers. Their theoretical predictions are also backed up by results from an empirical investigation.

Poor facility management and too low supply of adequate public facilities can adversely affect service production. The education sector has received particular attention, see, e.g. Hopland (2012, 2013, 2014a), Hopland and Nyhus (2015), Green and Turrell (2005), Lavy and Bilbo (2009), and COSLA and the Scottish Government (2009).

3. Local and central governments

Local governments as suppliers of local public goods

The extent of, and importance of, local governments as providers of important public goods is reflected in the overwhelming academic literature that discusses various aspects of local public service production (see e.g. Reback, 2005; Hilber and Mayer, 2009 for the USA, Ridder *et al.*, 2005 for Germany, De Borger and Kerstens, 1996 for Belgium, Elander and Montin, 1990 for Sweden, and Aulich, 1999 for Australia).

For some more details, we look at Norway as an example. Norwegian local governments are the main providers of welfare services such as primary and lower secondary education, primary healthcare, and social services. The local public sector accounts for nearly 50 percent of government consumption and their revenues make up 18 percent of GDP. The local governments have substantial discretion in the allocation of resources between services, but are heavily regulated on the revenue side. The main revenue sources are local taxes and grants from the central government. Most taxes are of the revenue sharing type, where efficient limits on local tax rates have been in place for the last 35 years.

Local government buildings make up as much as a quarter of all non-residential buildings in Norway. Schools make up nearly half of the total building mass and is the most important building type, followed by nursing homes (22 percent), office buildings (11 percent), and childcare centers (7 percent)[5]. In addition, the building mass includes local culture centers (*kulturhus*), warehouses, and sports facilities. On average the building mass amounts to 50 m^2 per employee.

Central government monitoring of local governments

In most countries, the central government funds the local governments to some extent. It is thus obviously of great interest for central governments to monitor and analyze how efficient the local governments are. To illustrate methods for and challenges in measuring local government efficiency, we again turn to Norway as an example.

A main challenge for analysis of public sector efficiency is how to measure production. The richest available measure used by the Norwegian central government is an aggregated output measure developed by the Norwegian Advisory Commission on Local Government Finances (*Teknisk Beregningsutvalg for Kommunal og Fylkeskommunal Økonomi, TBU*). Since 2001, the commission has calculated and published indicators of aggregated output, as well as indicators on output in up to seven different service sectors. This work is documented in Borge *et al.* (2008) and Borge and Tovmo (2009). The sectors included in the aggregate output measure account for about 75 percent of the local government budgets. The local governments provide most of the services themselves, but they also have the opportunity to finance private services production. Private service providers are, e.g. common in the kindergarten sector. Private production is included in the output measure.

In addition to the production index, an efficiency measure calculated and published by the Ministry of Local Governments is available for evaluation of local government efficiency. This measure is calculated using the data envelopment analysis method (see Farrel, 1957; Charnes *et al.*, 1978). The basic idea is that the efficiency of a production unit is measured relative to a best practice reference frontier, which is calculated from the data. This is a popular method for calculating efficiency in the public sector as it does not require information on neither input nor output prices, in addition to easily handling multiple output and input measures.

4. Discussion

For the sake of readability, we place most of the mathematical details in the Appendix, and discuss only the outcomes of the game-theoretical model in this section. Non-technical readers can thus follow the arguments in the main text, while those interested in the details can study the full derivations in the Appendix. Assume that a country exists of n local governments, which each holds a stock of facilities denoted x_i ($i \in \{1, 2, \ldots, n\}$). The local governments share a common utility function $u(x_i)$, which represents the benefit to the local taxpayers from facilities supplied by their own local government. The cost function $k_i c(x_i)$ represents all costs related to the stock of facilities, including both the direct investment cost, maintenance, and the administrative costs related to collecting revenues via local taxation. The parameter $k_i > 0$ represents efficiency, where a small k_i implies low costs, and thus an efficient local government. As is standard in economic theory, we assume concave utility and convex costs. Concave utility means that an increase in utility is appreciated more by those who have little in the first place. Convex costs imply that economies of scale are fully utilized, so that marginal costs increase with increased supply. Technically, these assumptions imply $u' > 0$, $u'' < 0$, $c' > 0$, and $c'' > 0$. In addition, we have $u(0) = 0$ and $c(0) = 0$.

The local government wishes to maximize the local utility of facilities, net of costs, summarized in the objective function $u(x_i) - k_i c(x_i)$. We denote the optimal supply of facilities from the viewpoint of the local government x_i^{loc}, and this is determined by the first-order condition:

$$u'\left(x_i^{loc}\right) = k_i c'\left(x_i^{loc}\right). \tag{1}$$

Implicit differentiation of (1) gives:

$$\frac{\partial x_i^{loc}}{\partial k_i} = \frac{c'\left(x_i^{loc}\right)}{u''\left(x_i^{loc}\right) - k_i c''\left(x_i^{loc}\right)} < 0.$$

That is, low-efficiency local governments (with a large k) have a lower optimal amount of facilities than high-efficiency local governments. We formulate the positive externality as a fixed fraction ω of the resources allocated to facilities within each local government. The externality benefits the other $n-1$ communities equally. Moreover, the externality is a pure public good. This means that the enjoyment of the good by any given local community does not reduce the availability of the good to other local communities. The benefit to society as a whole from facilities in local community i is thus:

$$u(x_i) + x_i[\omega(n-1)].$$

The per unit externality $\omega(n-1)$, henceforth denoted b, gives an increase in the social benefit that the central government takes into account, whereas the local governments do not. The socially optimal level of facilities, obtained by maximizing the objective $\max_{x_i \geq 0} u(x_i) + x_i b - k_i c(x_i)$ is denoted x_i^{cen}, and determined from the optimum condition (note that we in the remainder skip the subscript i for notational convenience):

$$u'(x^{cen}) + b = kc'(x^{cen}). \tag{2}$$

The difference between (1) and (2) arises from the fact that the local governments do not take into account the positive externality b, and thus provide less facilities than what is optimal from the viewpoint of the central government.

We now study how the social optimum can be reached using classical contract theory. The central government should design a contract where it offers local governments a transfer to make them accept to increase their supply of facilities. For the sake of simplicity, we assume that the central government finances the transfer by an ad hoc tax, thus avoiding a specific treatment of the central government's budget constraint. However, taxation implies costs to society as a whole, since economic activity is distorted. Individual taxpayers will rationally try to divert their activities from taxed to non-taxed areas to avoid the tax, resulting in an adjustment that does not represent the preferences of the households (Pigou, 1962; Atkinson and Stiglitz, 1980)[6]. This represents an additional cost of taxation to society that must be taken into account by the central government. We measure this cost as simply as possible, as a fixed fraction γ of the transfer T. The central government maximizes the total benefit of facilities, net of investment, and taxation costs, as expressed in the objective function $u(x) + bx - \gamma T - kc(x)$. The local governments simply regard the transfer as additional income, conditioned upon accepting the contract.

The central government also faces the constraint that the local governments must be at least as well off by accepting the contract as they were before when it was offered. That is, the local governments' utility must be at least as large as its reservation utility, which we define as the net utility obtained by the optimal amount of facilities without the contract. If the contracts do not satisfy this participation constraint, expressed as $T + u(x) - kc(x) \geq u(x^{loc}) - kc(x^{loc})$, the local governments will decline the contract and stick to the original supply of facilities.

The contracts under symmetric information

We start out by analyzing the problem assuming that the central government has full information with respect to the efficiency of local governments. That is, a case where the central government's tools to monitor the local governments, as discussed in Section 3, work perfectly (or at least close to perfectly) to reveal the efficiency of the local governments. The solution obtained in this subsection will serve as a benchmark for the subsequent study of the distortions created by asymmetric information. When k is observable and we assume an interior solution (x, $T > 0$) we arrive at:

$$u'(x^{cen}) + \frac{b}{1+\gamma} = kc'(x^{cen}). \tag{3}$$

Equation (3) shows that the marginal benefit from facilities equals the marginal costs, corrected for the social cost of taxation. This condition determines the optimal amount of facilities. We denote the optimal transfer under symmetric information T^{sym}. This is determined by the condition:

$$T^{sym} = u\left(x^{loc}\right) - kc\left(x^{loc}\right) - [u(x^{cen}) - kc(x^{cen})], \tag{4}$$

which implies that the central government only covers the difference between the net utility with and without the contract. Since the transfer implies a social cost of taxation, it should be kept as small as possible without deterring the local government from taking part in the project.

Equation (3) shows that the optimal amount of facilities decreases with γ, implying that the distortion leads to a smaller transfer. $\gamma = 0$ implies that the transfer should equal the positive externality. Intuitively, in the absence of externalities (i.e. $b = 0$), we arrive at the same optimality condition as the local governments do without taking the externality into account. Hence, the central government will not intervene by demanding more facilities and handing out a larger grant in this special case. It is also evident that the optimal x^{cen} decreases with k, i.e. the central government, reasonably enough, requires the highly efficient local governments to provide more facilities. However, which local governments that get the highest transfer is not clear, since there are two opposing effects at play. Because unit costs are higher for less efficient governments, less efficient local governments should get a larger transfer per unit local public facility provided. However, since the central government demands a larger amount of facilities from the highly efficient local governments, the total transfer they receive can still be larger. The overall effect on the optimal transfer in the symmetric information case is thus ambiguous with general function forms.

The contracts under asymmetric information

We now consider the case where the efficiency of each local government is not known to the central government. Hence, we are now studying a more realistic scenario where the monitoring tools discussed in Section 3 do not give the central government full information about how efficient the local governments are.

We assume that local governments can be classified as either "highly efficient" or "less efficient" in supplying local public facilities. Technically, we distinguish them by the size of k, which can be either k_{eff} or k_{ineff}. We set $k_{eff} < k_{ineff}$, i.e. local governments with a small k are more efficient in providing facilities than those with a large k.

We denote the share of highly efficient local governments p, and interpret this as the probability that a given local government is highly efficient. Consequently, $1-p$ is the probability that a given local government is less efficient. As the central government now faces an informational disadvantage, it risks granting too large a transfer to the highly efficient local governments. We will now discuss how the central government can design an agreement that induces the local government to reveal its true efficiency level[7]. We further study how correctly designed contracts will make the local governments rationally choose the contract intended for its level of efficiency. We then compare the solution obtained under asymmetric information to the first best symmetric information case studied in the previous subsection. The key is that the local governments will reveal their true effectiveness if the transfer and demanded amount of facilities for each efficiency level is set such that they satisfy a set of incentive compatibility constraints. We will see that this comes with an additional cost for the central government, which is referred to as informational rent in the adverse selection literature.

The central government's objective function under asymmetric information reads:

$$p\left[u\left(x_{eff}\right)+bx_{eff}-\gamma T_{eff}-k_{eff}c\left(x_{eff}\right)\right]+(1-p)\left[u\left(x_{ineff}\right)+bx_{ineff}-\gamma T_{ineff}-k_{ineff}c\left(x_{ineff}\right)\right]$$

here T_{ineff} and x_{ineff} are the transfer and required amount of facilities, respectively, determined for less efficient local governments, and T_{eff} and x_{eff} for highly efficient local governments. Furthermore, in order to secure that each local government chooses the contract intended for it, all local governments must be better off by accepting the contract designed for their efficiency level rather than that for the other level.

For the efficient type, the incentive compatibility condition reads $T_{eff}+u(x_{eff})-k_{eff}c(x_{eff})\geqslant T_{ineff}-u(x_{ineff})+k_{eff}c(x_{ineff})$, and similarly for the inefficient type. The central government now maximizes its objective with these additional restrictions, and one participation constraint for each level of efficiency. It is useful to note that the participation constraint for highly efficient local governments is always satisfied. Because the efficient local government produces each unit of facilities cheaper, a contract that is satisfactory for less efficient local governments will always satisfy the participation constraint of the highly efficient ones as well. The following conditions define the optimal contract menu (the superscript for the optimal transfer T^{asym} clarifies that this is the optimal transfer under asymmetric information):

$$u'\left(x_{eff}^{cen}\right)+\frac{b}{1+\gamma}=k_{eff}c'\left(x_{eff}^{cen}\right), \tag{5}$$

$$u'\left(x_{ineff}^{cen}\right)+\frac{b}{1+\gamma}=k_{ineff}c'\left(x_{ineff}^{cen}\right)\left(1+\frac{\gamma}{1+\gamma}\frac{p}{1-p}\frac{k_{ineff}-k_{eff}}{k_{ineff}}\right), \tag{6}$$

$$T_{eff}^{asym}+u\left(x_{eff}^{cen}\right)-k_{eff}c\left(x_{eff}^{cen}\right)-\left[u\left(x_{eff}^{loc}\right)-k_{eff}c\left(x_{eff}^{loc}\right)\right]=\left(k_{ineff}-k_{eff}\right)c\left(x_{ineff}^{cen}\right), \tag{7}$$

$$T_{ineff}^{asym}+u\left(x_{ineff}^{cen}\right)-k_{ineff}c\left(x_{ineff}^{cen}\right)-\left[u\left(x_{ineff}^{loc}\right)-k_{ineff}c\left(x_{ineff}^{loc}\right)\right]=0. \tag{8}$$

Equation (5) is identical to (3), i.e. from the symmetric information case, and states that the central government demands the same amount of facilities from the highly efficient local governments as in the symmetric information case. However, (7) gives that the transfer to highly efficient local governments will be larger under asymmetric information than otherwise, crf. Equation (4). The optimal transfer differs from the symmetric information case by the term $(k_{ineff}-k_{eff})c(x_{ineff})$. This is the highly efficient local government's informational rent; the additional transfer required from the central government for the highly efficient local governments to reveal their true efficiency level. It is equal to the difference in costs between the two efficiency levels, for providing x_{ineff}. Equation (6) shows that the central government demands less facility from the less efficient local governments, both compared to the highly efficient local governments (Equation (5)) and to the full information case (Equation (7)). This is to make the less efficient local governments' contract less attractive for the highly efficient local governments. Some special cases are worth noting. First, if $p=0$, i.e. there are no highly efficient local governments, the solution collapses to the perfect information case. Second, in the opposite case where p approaches 1 (i.e. all are highly efficient), $c'(x_{ineff}^{cen})$must approach 0 for (6) to hold. If $c'(0)>0$, there is some $p<1$ above which contracts are only offered to the highly efficient local governments. Third, if taxes are not distortionary, i.e. $\gamma=0$, all local governments are required to provide the same amount of facilities, and obtain the same transfer. In the case with $x_{eff}^{cen}=x_{ineff}^{cen}$, the highly efficient local governments obtain the highest possible informational rent, which is $(k_{ineff}-k_{eff})c(x_{eff}^{cen})$. Finally, (8) reveals that the less efficient local governments will be just as well off as without taking part in the project, no extra rent is granted.

5. Concluding remarks

The findings in this paper provide a rationale for central government intervention in local government facilities management through central investment grants, and guidance regarding the design of contracts between the central and local governments. Importantly, the local governments have superior information about their efficiency in supplying local government facilities, and the central government must take this into account when designing the investment grant contracts. We analyze this using the classical adverse selection game theory model. The findings show that that central government should offer a contract which stimulates highly efficient local governments to supply more facilities and in exchange give high investment grants to these local governments. Less efficient local governments receive less investment grants and are required to supply less facilities. Note that in the asymmetric information case we are able to say unambiguously that the high-ability local government will get more grants.

The optimal contracts derived in this paper increase efficiency in the sense that contracts are fitted to various ability levels. The overall welfare implications are beneficial, first because all local governments are at least as well off compared to the no-transfer situation, otherwise they will not accept the contract. Second, all local governments further benefit from the increase in total local public facilities due to the positive externalities. There are some redistribution effects to consider. Since highly efficient local governments receive a larger grant than the less efficient ones, the difference in local facilities supplied will increase. Hence, even though all benefit from the policy, some will benefit more than others. We thus face a classic trade-off between equity and efficiency in this situation. However, the increase in overall welfare can, in principle, be redistributed through other channels. In addition, the contracts proposed in the present paper can in the long run also help to resolve this dilemma. The choice of which contract to accept reveals the abilities to the local government. With this new information, the central government can take actions to increase the efficiency in low-ability local governments.

Notes

1. Note that a central government investment program can be problematic, since it gives local governments incentives to underspend on maintenance, expecting that the central government covers the maintenance backlog (Hopland, 2015). In order to reduce this problem, known as moral hazard in game theory, we assume that the central government announces the program shortly before the payment of the transfer. This reduces the local governments' opportunities to behave strategically, since they do not expect to receive additional grants based on the condition of their facilities. Further, the transfer is paid only once, and is earmarked for projects that would otherwise not have taken place, in order to avoid spillover to other budget posts.

2. The model can, relatively simply, be extended to allow for more than two levels of efficiency. In its most general form, the model defines a continuum of different efficiency levels. In terms of reducing problems caused by asymmetrical information, a continuum of contracts, i.e. individually designed contracts for each local government is the most efficient.
3. A similar examination is carried out by Rattsø (1999) on Norwegian data. As Holtz-Eakin and Rosen (1989, 1993) said, he cannot reject that local public investments are determined by rational forward-looking behavior.
4. They do not define an optimal maintenance strategy, though. Hopland and Kvamsdal (2016) evaluate optimal maintenance strategies for local governments, and show that it is not trivial to define the optimal level at any given time.
5. Around half of all childcare centers are privately owned and are not included in the figures.
6. A familiar example is income tax, which may negatively affect the household's labor supply, thus lowering production of goods and services and making all households worse off.
7. Technically, this is a characteristic of the optimal policy, which follows from Myerson's (1979) revelation principle.

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Appendix

Technical appendix

Deriving Equations (1) and (2) in the paper

The local government wishes to maximize the local utility of facilities, net of costs, and thus solves the optimization problem $\max_{x_i \geqslant 0} u(x_i) - k_i c(x_i)$ (in the remainder we skip the subscript i). By taking the derivative of this w.r.t. x and setting it equal to 0, we get Equation (1) in the paper. When taking the positive externality into account the maximization problem is $\max_{x \geqslant 0} u(x)+bx-kc(x)$. By taking the derivative of this w.r.t. x and setting it equal to 0, we arrive at Equation (2) in the paper.

Derivation of the first-order condition under symmetric information

The central government maximizes overall social welfare, net of costs, i.e. $u(x) + bx - \gamma T - kc(x)$, while each local government, on the other hand, regards the transfer as income and maximizes $T + u(x) - kc(x)$. The contracts must satisfy the participation constraint $T + u(x) - kc(x) \geqslant u(x^{loc}) - kc(x^{loc})$, where x^{loc} is defined from Equation (1) in the paper. When k is observable, the central government's optimization problem implies the Lagrangian $L = u(x) + bx - \gamma T - kc(x) + \lambda\ [T + u(x) - kc(x) - u(x^{loc}) + kc(x^{loc})]$, and the corresponding Kuhn-Tucker conditions:

$$u'(x)(1+\lambda)+b \leqslant kc'(x)(1+\lambda), \quad x \geqslant 0, \quad [u'(x)(1+\lambda)+b-kc'(x)(1+\lambda)]x = 0, \tag{A1}$$

$$\gamma \geqslant \lambda, \quad T \geqslant 0, \quad (\gamma-\lambda)T = 0, \tag{A2}$$

$$T+u(x)-kc(x) \geqslant u\left(x^{loc}\right)-kc\left(x^{loc}\right), \quad \lambda \geqslant 0, \quad \lambda\left[T+u(x)-kc(x)-u\left(x^{loc}\right)+kc\left(x^{loc}\right)\right] = 0. \tag{A3}$$

An interior solution with $T > 0$ implies $\gamma = \lambda$ from (A2). Using this in (A1) with $x > 0$ gives Equation (3) in the paper.

Derivation of the first-order condition under asymmetric information

The incentive compatibility constraints $T_{ineff} + u(x_{ineff}) - k_{ineff}\, c(x_{ineff}) \geqslant T_{eff} + u(x_{eff}) - k_{ineff} c(x_{eff})$ and $T_{eff} + u(x_{eff}) - k_{eff} c(x_{eff}) \geqslant T_{ineff} + u(x_{ineff}) - k_{eff} c(x_{ineff})$ imply that local governments are not better off choosing a contract that is meant for the other type. Hence, they have no incentive to hide their true ability level once these conditions are satisfied. The central government maximizes expected social welfare subject to the incentive compatibility constraints and the participation constraint for less efficient local governments. With p denoting the share of efficient local governments, this implies the Lagrangian:

$$L = p\left[u(x_{eff}) + bx_{eff} - \gamma T_{eff} - k_{eff}c(x_{eff})\right] + (1-p)\left[u(x_{ineff}) + bx_{ineff} - \gamma T_{ineff} - k_{ineff}c(x_{ineff})\right]$$
$$+\lambda\left[T_{ineff} + u(x_{ineff}) - k_{ineff}c(x_{ineff}) - u\left(x_{ineff}^{loc}\right) - k_{ineff}c\left(x_{ineff}^{loc}\right)\right]$$
$$+\mu\left[T_{eff} + u(x_{eff}) - k_{eff}c(x_{eff}) - T_{ineff} - u(x_{ineff}) + k_{eff}c(x_{ineff})\right]$$
$$+\delta\left[T_{ineff} + u(x_{ineff}) - k_{ineff}c(x_{ineff}) - T_{eff} - u(x_{eff}) + k_{ineff}c(x_{eff})\right],$$

and the corresponding Kuhn-Tucker conditions:

$$\left[pb + (p+\mu-\delta)u'(x_{eff})\right] \leqslant \left[k_{eff}(p+\mu) - k_{ineff}\delta\right]c'(x_{eff}), \quad x_{eff} \geqslant 0,$$
$$\left\{\left[pb + (p+\mu-\delta)u'(x_{eff})\right] - \left[k_{eff}(p+\mu) - k_{ineff}\delta\right]c'(x_{eff})\right\}x_{eff} = 0, \tag{A4}$$

$$\left[(1-p)b + (1-p+\lambda-\mu+\delta)u'(x_{ineff})\right] \leqslant \left[k_{ineff}(1-p+\lambda+\delta) - k_{eff}\mu\right]c'(x_{ineff}), \quad x_{ineff} \geqslant 0,$$
$$\left\{\left[(1-p)b + (1-p+\lambda-\mu+\delta)u'(x_{ineff})\right] - \left[k_{ineff}(1-p+\lambda+\delta) - k_{eff}\mu\right]c'(x_{ineff})\right\}x_{ineff} = 0, \tag{A5}$$

$$p\gamma \geqslant \mu - \delta, \quad T_{eff} \geqslant 0, \quad (p\gamma - \mu + \delta)T_{eff} = 0, \tag{A6}$$

$$(1-p)\gamma \geqslant \lambda - \mu + \delta, \quad T_{ineff} \geqslant 0, \quad ((1-p)\gamma - \lambda + \mu - \delta)T_{ineff} = 0. \tag{A7}$$

T_{eff}, $x_{eff} > 0$ implies $\gamma p = \mu - \delta$ in (A6). In (A4), this gives $p[b + (1+\gamma)\,u'(x_{eff}) - (1+\gamma)k_{eff}c'(x_{eff})] = \delta(k_{eff} - k_{ineff})c'(x_{eff}) \Rightarrow \delta = 0$ since $k_{eff} - k_{ineff} < 0$. Hence, the incentive compatibility constraint for less efficient local governments does not bind. The incentive compatibility constraint for the highly efficient local governments binds, since $\mu = \gamma p > 0$. With T_{ineff}, $x_{ineff} > 0$, (A5) and (A7) give $\gamma p = \lambda - (1-p)\gamma \Rightarrow \lambda = \gamma > 0$, i.e. the participation constraint for the less efficient local governments binds. The incentive compatibility constraints give $k_{ineff}[c(x_{eff}) - c(x_{ineff})] \geqslant T_{eff} + u(x_{eff}) - [T_{ineff} + u(x_{ineff})] \geqslant k_{eff}[c(x_{eff}) - c(x_{ineff})]$. Since $k_{ineff} > k_{eff}$, we then have $c(x_{eff}) - c(x_{ineff}) > 0$ and hence $x_{eff} > x_{ineff}$. Combining these insights gives Equations (5)-(8).

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