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Green public procurement as an environmental policy instrument: cost effectiveness

Abstract

Estimates by the European Commission indicate that public authorities within the European Union typically purchase goods and services corresponding to approximately 16 percent of GDP per annum. Hence, it is believed, private firms can be stimulated to invest in less polluting production technologies if the market power of public bodies is exerted through Green Public Procurement (GPP) policies and legislation. It is commonly argued that there are considerable possibilities for cost-effective GPP. The aim of this paper is to scrutinize this argument by specifically answering the question whether GPP can work as a cost-effective environmental policy instrument in terms of leading firms to reduce emissions at least cost to society. Not reducing emissions cost-effectively is a waste of resources. The main finding shows that GPP does not generate cost-effective outcomes, which also countries outside EU, like the U.S., should take into account when considering conducting environmental policy via GPP.

Keywords: abatement, auctions, compliance cost, environmental objectives, green technology, investments, purchasing, sustainability.
JEL Classification: H57, Q01, Q28.

Introduction

In Europe and most other countries public purchase constitutes a significant part of the economy. Estimates show that public authorities within the European Union (EU) purchase goods and services corresponding to about 16 percent of the EU Gross Domestic Product annually (European Commission, 2008; Marron, 2003). Public authorities are therefore, by its market power, commonly regarded as having the power to influence production and consumption in society towards sustainability. Officially, Green Public Procurement (GPP) is in these circumstances regarded as an important, flexible, and powerful mean to achieve sustainable development (e.g. Tarantini, Loprieno and Porta, 2011).

The European Commission is for example very clear in its ambition of implementing GPP, making an effective contribution to environmental objectives. According to European Commission (2008, p. 2) there are studies that have confirmed the considerable scope for cost-effective green public procurement[1]. In the present paper this particular statement is scrutinized within the framework of welfare economics, accounting for effectively achieving environmental and natural resources objectives adopted by a country's parliament[2]. The purpose is explicitly to find out whether GPP can work as a cost-effective environmental policy instrument in terms of leading to emissions being reduced at least cost to society. Not achieving the objectives cost-effectively gives rise to opportunity costs, which can be seen as a waste of resources.

The European Commission (2008) states that GPP is to be understood as: "*...a process whereby public authorities seek to procure goods, services and works with a reduced environmental impact throughout their life cycle when compared to goods, services and works with the same primary function that would otherwise be procured*" (p. 4). GPP includes environmental, climate and energy ambitions which, in this paper, also will be referred to with GPP. By addressing negative environmental externalities, and following previous research by Marron (1997, 2003), we regard GPP as an environmental policy instrument and analyze it from a welfare economics setting.

If GPP not leads to emissions being reduced at least cost to society, there is a welfare loss that possibly outweighs environmental gains achieved by GPP and other gains achieved by the procurement auction per se, such as upholding competition. In this paper we explicitly ask the question: Is GPP a cost-effective environmental policy instrument? Answering this question is the major contribution to the literature within welfare economics, also providing relevant policy implications.

The paper is organized as follows. In the following section previous studies on GPP are discussed in more detail. The regulation and practice of GPP are presented in section 2. In section 3 we present a noble theoretical model to analyze GPP and cost effectiveness, and in section 4 we bring forward the importance of understanding what different aspects of environmental and resource problems different types of environmental criteria in public procurement address. Finally, a discussion and some conclusions are provided in the last section.

[1] In the communication the European Commission (2008) does not explicitly reveal any of those studies.

[2] Note that we do not question the environmental and natural resources objectives adopted by a country's parliament. We assume that the objectives are set optimally in a welfare economics perspective.

1. GPP – previous research

The internationally peer-reviewed literature addressing GPP is within the field of economics very scarce (e.g. Testa, Iraldo, Frey and Daddi, 2012). One exception is Marron (1997) who identifies weaknesses in the functioning of GPP as an environmental policy instrument. Marron departures from a model where the public sector goes from conventional to greener consumption and illustrates that the market mechanisms counteract with the green intensions. This conclusion persists even after comparing GPP to other policy instruments (Marron, 2003). However, Marron does not discuss GPP from the perspective of cost-effectiveness.

Another aspect of actual environmental impact is discussed in D'Amoto (2006), who finds the organization of green public purchases to be important for the outcome. A decentralized structure characterized by non-cooperation between the environmental agency and the procurement agency results in a downward distortion in environmental quality. How the procurements are organized is also found to be important for the outcome of GPP in the study by Testa et al. (2012).

Commonly, previous studies on the subject have regarded GPP as an established environmental policy measure. Without any ambition to consider welfare effects and use of resources they focus only on the private potential benefits of GPP, e.g. Cerin (2006), Sterner (2002) and Parikka-Alhola (2008). In this spirit, some studies focus on national initiatives in different parts of the world, e.g. the Chinese green public procurement program (Geng and Doberstein, 2008; Qiao and Wang, 2011), the French public healthcare (Oruezabala and Rico, 2012), or experiences from South-Africa (Bolton, 2008) and Norway (Michelsen and de Boer, 2009).

Here we show that GPP is not a cost-effective environmental policy instrument. This finding is not only valid for public procurements within the EU, but also for public procurements in countries outside the EU.

2. GPP – regulation and practice

The institutional settings concerning GPP in Europe are explicitly based on public procurement as defined by the EU procuring directives, 2004/17/EC and 2004/18/EC[1]: "*Public procurement means the measures implemented by a contracting authority with the aim of awarding a contract or concluding a framework agreement regarding products, services, or works*" (Article 13)[2]. The usage of this definition as a departure point for our analysis does not limit the legitimacy of our results. The discussion in this paper is basically valid also for public procurement in countries outside Europe.

GPP means in practice that public contracts are allocated based on green qualification and award criteria, and green contract clauses[3]. In general, a specific procurement involves a competitive bidding process where a set of potential suppliers compete for one or several contracts. Based on price and quality, the contracts are allocated to one, or a subset, of the potential suppliers (e.g., Che, 1993).

More specifically, the EU procurement directives stipulate sealed tendering and after having received tenders from the potential suppliers the contracting authority stands before a process of evaluation. The tender evaluating process can be characterized as a two-step procedure. First, there is a supplier post-qualification screening[4]. The mandatory green requirements, enforcing GPP, may be in terms of technical specifications and address, e.g., emissions to air and water, energy consumption, waste generation, etc. The technical specification can include material selection, chemical content and characteristics of the product (Palmujoki, Parikka-Ahola and Ekroos, 2010). The potential suppliers that fulfill the mandatory requirements then qualify for the second step of the evaluation process, i.e., the contracting authority identifying the winning tender and awarding the contract.

The idea of GPP is modeled in this paper as a process where potential suppliers on a market for a conventional good are given incentives to invest and adjust to a required environmental standard. The choice of environmental qualification and award criteria must respect the single market principles which serve to uphold competition: equal treatment, transparency, non-discrimination, proportionality, and mutual recognition (e.g. Palmujoki et al., 2010). Furthermore, the environmental qualification and award criteria must be linked to the subject matter of the contract[5].

Finally, one necessary condition (not sufficient though) for GPP to work satisfactory as an environmental policy instrument is that it actually has a

[1] Directive 2004/17/EC concerns contracts within the sectors of water, energy, transport and postal services. Directive 2004/18/EC concerns contracts in public work, public supply, and public service.

[2] Note that this definition on public procurement excludes auctions of tradable permits and nature conservation contracts.

[3] See Government Procurement Agreement (GPA) and the EU procurement directives.

[4] In e.g. the US it is quite common with pre-qualification screening. This is not equally common in Europe. Instead post-qualification is applied. See e.g. Wan and Beil (2009) for an auction with supplier post-qualification screening. However, in contrast to our model, they model an auction where there is no cost associated with entry.

[5] The subject matter can take the form of a basic description of the product, or of a performance based definition (European Commission, 2011).

positive impact on the environment. However, positive impacts are not as obvious as it might seem at first view. Independently of type of environmental requirements specified in a separate GPP, they may have more or less environmental impacts. If the environmental requirements mainly attract already "green" suppliers and the "conventional" ones therefore choose not to enter the procurement auction, there will be small or no positive effects on the environment[1]. GPP will in this case only redistribute the authority's purchase from conventional to greener-suppliers (substitution policy), the conventional ones continuing supplying less environmentally demanding buyers. This will in turn affect the relative price. The net-effect on the environment will depend on the sensitivity of market demand and supply to changes in relative prices, as well as the market power of the separate GPP auction (Marron, 1997)[2].

3. GPP – theoretical model

Before outlining the theoretical model, it is important to clarify some crucial starting points. Firstly, GPP is just one policy instrument among other instruments at disposal in practice. For instance, a unit tax on emissions is imposed at the national level and all relevant emission sources are subject to the tax. From that point of view, to be environmentally effective compared to the tax, it is crucial that as many potential suppliers as possible adjust to the environmental standards implemented by GPP; not only the supplier that wins the contract. Therefore, when evaluating whether GPP is a cost-effective environmental policy instrument or not, we should not only consider the winner of the contract. Secondly, in reality there is no social planner that optimally coordinates all individual public procurement in a welfare economics setting. In practice, a procurement is usually implemented independently of other procurements. Hence, our theoretical model describes a typical public procurement auction and seeks the answer to whether GPP reduces emissions cost-effectively or not. The outcome of the analysis may then be aggregated to incorporate the outcomes of all separate procurements. That is, if one procurement function as a cost-effective/ineffective environmental policy instrument, so does the aggregate.

We analyze GPP as an environmental policy instrument assuming that the politicians on some level (e.g. state, county or local) decide GPP to be implemented. Then, when procuring a good, service or works, GPP is actually implemented by the civil servant at the contracting authority, e.g., a municipality. The authority organizes a procurement auction with the aim to allocate a contract to one supplier. The procurement can be said to have two functions. It will lead to a purchase of something that the society needs to fulfill its mission to the citizens. The procurement is also used as an environmental policy instrument with the aim that it will lead to reduced emissions in a cost-effective manner.

Formally, consider an economy where $i = 1,\ldots,N$ heterogeneous suppliers with conventional technologies produce a single good, Q, amounting to $q = \sum_{i=1}^{N} q_i$ [3]. The process of producing Q simultaneously generates emissions of a uniformly mixing pollutant, Z, amounting to $z = \sum_{i=1}^{N} z_i$, where $z_i \neq z_j$ [4]. This being so, politicians in the society have the intension to reduce the emissions in accordance to the environmental objective(s). Maintaining the amount q, this is the same as saying that environmental productivity in society in terms of produced amount of good output per unit of emission, q/z, must increase.

Consider a contracting authority who in a specific procurement allocates one contract by competitive bidding. The contract specifies the public procurement quantity $q^{pp} \leq q$ of the marketable product. As there are political ambitions of reducing emissions generated in this particular market, the politicians have decided that necessary reductions are to be achieved through GPP[5]. The necessary total emission reduction in society is specifically set to $\Delta z = z - z^*$, where z^* is the politically set sustainable level of emissions. Accordingly, via the criteria the authority translates the objective Δz, or z^*, to correspondingly needed criteria in the call for tenders, e.g., by specifying a certain technology requirement that is the same for all N potential suppliers. This means that the organization of the procurement auction and the environmental requirements comply with the earlier mentioned single market principles (see e.g. Palmujoki et al., 2010).

[1] From a welfare economics point of view it is nearly impossible to know when a firm is to be regarded as being green. However, we simply say that a green firm satisfies the environmental criteria ex ante the procurement auction and a conventional firm does not, and therefore has to adjust its environmental performance before entering the procurement auction.

[2] However, to our knowledge, there are no scientific studies that empirically confirm the market power assumption commonly used as an argument by EU when advocating increased implementation of GPP.

[3] Assuming N suppliers is not crucial for our findings. It is a simplifying assumption.

[4] A uniformly mixing pollutant is a pollutant of which the concentration does not vary spatially, irrespective of where it actually is emitted. Examples of uniformly mixing pollutants are greenhouse gases, e.g., carbon dioxide.

[5] A simplifying assumption is that there are no other environmental policy policy instruments in effect with the same environmental objective as that one of the GPP. Allowing for other instruments, such as taxes already being in effect, would not make the environmental consideration in procurement auctions less difficult from an effectiveness point of view.

Explicitly, the contracting authority imposes on each cost-minimizing potential supplier a minimum required level of technology in production in accordance to the following function[1]:

$$T^* = f\left(z^*, N\right). \tag{1}$$

The environmental requirements in the procurement auction are a function of the environmental objective set by the politicians, and the number of potential suppliers, with $T^*_{z^*} \geq 0$ and $T^*_N \leq 0$.

Important to consider is that the minimum required level of technology, T^*, will have differing enforcing impact on potential suppliers due to them being heterogeneous in their ex ante procurement technology level, T_i (a higher T_i is equivalent to a greener technology). Hence, the technology change necessary to meet the minimum technology requirement is for supplier i:

$$\Delta T_i = T^* - T_i, i = 1,..., N, \text{ and } \Delta T_i \neq \Delta T_j. \tag{2}$$

The greener technology ex ante the procurement, T_i, the less technological units, ΔT_i, the potential supplier needs to invest in to achieve the required technological level, T^*, and to qualify as a supplier. As the magnitude of the needed investment differs between suppliers depending on differences in their ex ante technology, the cost of adjusting to criteria is as follows:

$$CA_i = g\left(T_i; T^*\right), \; i = 1,..., N, \text{ and } CA_i \neq CA_j, \tag{3}$$

where $CA_{T_i} \leq 0$, $CA_{T_iT_i} \geq 0$. Clearly, as environmental performance differs between potential suppliers ex ante the procurement auction, their total cost of adjustment (or compliance) to reduce emissions will also differ.

Proposition 1: Potential suppliers, i and j, being heterogeneous in ex ante procurement environmental performance, T_i and T_j, respectively, their cost of adjusting the last technological unit will differ, i.e., $MCA_i \neq MCA_j$. GPP is therefore inconsistent with the necessary condition for cost-effective emission reduction.

The necessary condition for cost-effectiveness, $MCA_i = MCA_j$, states that cost minimizing suppliers adjust to environmental criteria so that they end up with the same marginal cost of adjustment, and that the total emission reduction therefore will be achieved at least cost to society (this is explained in Appendix)[2]. Given the assumptions made GPP is inconsistent with this condition[3].

Note that so far we have made the following strong assumptions, basically in favor of GPP. The assumptions are: (1) All N potential conventional suppliers participate in the GPP auction; (2) the environmental requirement in the auction is binding for all N suppliers; (3) perfect information on the market, i.e., the contracting authority knows the technology level, T^*, that, spread among all N suppliers, will contribute to the achievement of the society's environmental objective, i.e., $\sum_i^N \Delta T_i$ leads to Δz.

The explanation to the non-cost-effective outcome can be referred to the single market principles of non-discrimination and equal treatment in the EU procurement directives. Strictly followed, the principles deny the authority to vary environmental requirements among suppliers, which makes it impossible to suit the requirements such that z^* is achieved, at the same time as the cost of adjustment becomes the same for all suppliers, i.e., $MCA_i = MCA_j$. However, relaxing the enforcement of non-discrimination and equal treatment will not make GPP a cost-effective environmental policy instrument in practice.

Proposition 2: Given that potential suppliers are heterogeneous in their production technologies, GPP will only satisfy the necessary condition for cost-effectiveness if the contracting authorities perfectly can predict the entry decision of supplier i, have perfect information about each individual supplier's production technology ex ante the procurement, T_i, and that it is legally allowed to tailor varying stringency of environmental criteria to each T_i. If these prerequisites do not prevail the necessary condition for cost-effectiveness requires that only the winning supplier adjust to the required environmental standard, or that firms are homogeneous in production technologies ex ante the procurement.

Proposition 2 reveals the difficulties of implementing GPP as a cost-effective environmental policy instru-

[1] We consider GPP as an administrative environmental policy instrument, which is in line with what is essentially observed in practice. For further details, see below.

[2] To refer the technology level to the actual emission level, the analysis is simplified by assuming the following relationship, $z_i = \beta \cdot T_i$, $\beta < 0$. For instance, in the case when $\beta = -1$ one additional technological unit corresponds to one reduced emission unit. Considering a more complex relationship between technologies and emissions does not alter the outcome of our analysis.

[3] Note that all suppliers adjusting to the same technological requirement does not necessarily lead to suppliers becoming completely homogenous in technology after the procurement auction. That is, even though all potential suppliers meet the same environmental criteria in terms of a certain technology level to be met, the technology requirement does not fully redesign the suppliers' production process. Most likely, in practice, the requirements address certain parts of the production process or product.

ment. In reality information is not likely to be perfect. Contracting authorities does not necessarily know the number of potential suppliers, *N*, and the entry decision of supplier *i*, i.e., does not exactly know what suppliers that will enter the procurement auction. Furthermore, even if the legal principles of the EU procuring directives would allow for individually specified environmental criteria it would be difficult to reach cost-effective emission reductions. The plain explanation is that the authority does not know the ex-ante procurement technology, T_i of each participating supplier. Accordingly, the authority is not able to tailor individually addressed criteria, T_i^*, that are necessary for satisfying $MCA_i = MCA_j$.

Basically, for GPP to be manageable as a cost-effective environmental policy instrument in practice, it is required that potential suppliers are homogenous in their production process, which in itself is an unreasonable assumption. Or, it is required that only the supplier with the lowest cost of adjusting to environmental criteria participate in the GPP auction. In this case, however, GPP is likely to have modest environmental effects.

European Union (2011) suggests that Life-Cycle Costing (LCC) *"...makes good sense regardless of a public authority's environmental objectives* (p. 42)". It is further suggested that LCC may also include costs of environmental externalities, which is referred to as Whole-Life Costing (WLC) analysis. To bring further perspectives on the propositions 1 and 2; even if WLC is applied, GPP will not be a cost-effective environmental policy instrument. Taking into account emissions throughout the whole production chain, including all subcontractors and all transports, requires even more information that the contracting authority hardly have.

The result above can be compared to the least cost tax theorem (Baumol and Oates, 1971; 1988), which states that a cost-effective policy outcome can be achieved by setting a per-unit tax on emissions. Specifically, each cost minimizing polluting supplier adjust to the tax rate such that they all end up with the same marginal adjustment cost. Hence, the emission reduction they achieve altogether will be achieved at least cost to the society. From a cost-effectiveness point of view a tax, or some other instrument with the same properties, is to be preferred over GPP. This is mainly explained by the design of GPP and discussed in more detail below.

4. GPP as a policy instrument

Assuming perfect information, the driving force behind the results is that heterogeneous potential suppliers in a specific procurement face the same set of environmental requirements. Formally, these requirements can either target emissions from the authority's own consumption of the product or emissions from the suppliers producing the product, or both. This is illustrated in Figure 1.

Given that the politicians decide to implement environmental and resource concerns in a procurement auction (defined as GPP in Box 1), the contracting authority can in practice target its own consumption of the product (Box 2) and/or the potential suppliers'processes of producing the product (Box 3). Having decided the target, GPP can then specifically target externalities (Box 4 or 6) and/or usage of resources (Box 5 or 7).

Furthermore, the authority can explicitly choose between different types of environmental criteria, or requirements. As it actually is practiced, GPP takes the character of being an administrative and/or quantitative environmental policy instrument. For instance, procuring transport services and simultaneously considering an externality (Box 6), e.g., global warming, an administrative requirement that target the production process would be that transports must be executed with biofuel vehicles. Further examples of how different requirements translate to different types of environmental instruments are found in Figure 1.

The distinction between GPP working as an administrative or a quantitative environmental policy instrument is very important from a welfare economics point of view. An administrative environmental requirement is typically referring to using a specific technology, and therefore stipulating how potential suppliers shall achieve the emission level. A quantitative requirement specifies, e.g., a maximally allowed emission level. Then, if deciding to enter the procurement auction, it is up to the supplier how to exactly achieve that level. In economics these both types of requirements are often referred to as *command-and-control*[1,2].

[1] Note that we do not consider GPP as a market-based, or economic, environmental policy instrument, as is done in, e.g., the Europe 2020 strategy (European Commission, 2010, p. 15). By economic instruments we refer to instruments that are incentive based and works through market price signals, such as taxes, charges, subsidies, and tradable permits. Economic instruments do not explicitly prescribe the use of a certain technology or that all firms must reduce emissions with exactly the same amount.

[2] The scientific debate on whether regard GPP as a command-and-control instrument or as an economic instrument is to our knowledge non-existent. However, based on own experience from the internal cleaning service and waste disposal transportation sectors in Sweden during 2000-2009, where criteria commonly are specified in terms of certificates or as in the case of transportation of waste disposal vehicles of a certain Euroclass, we consider GPP to being mainly an administrative environmental policy instrument in practice.

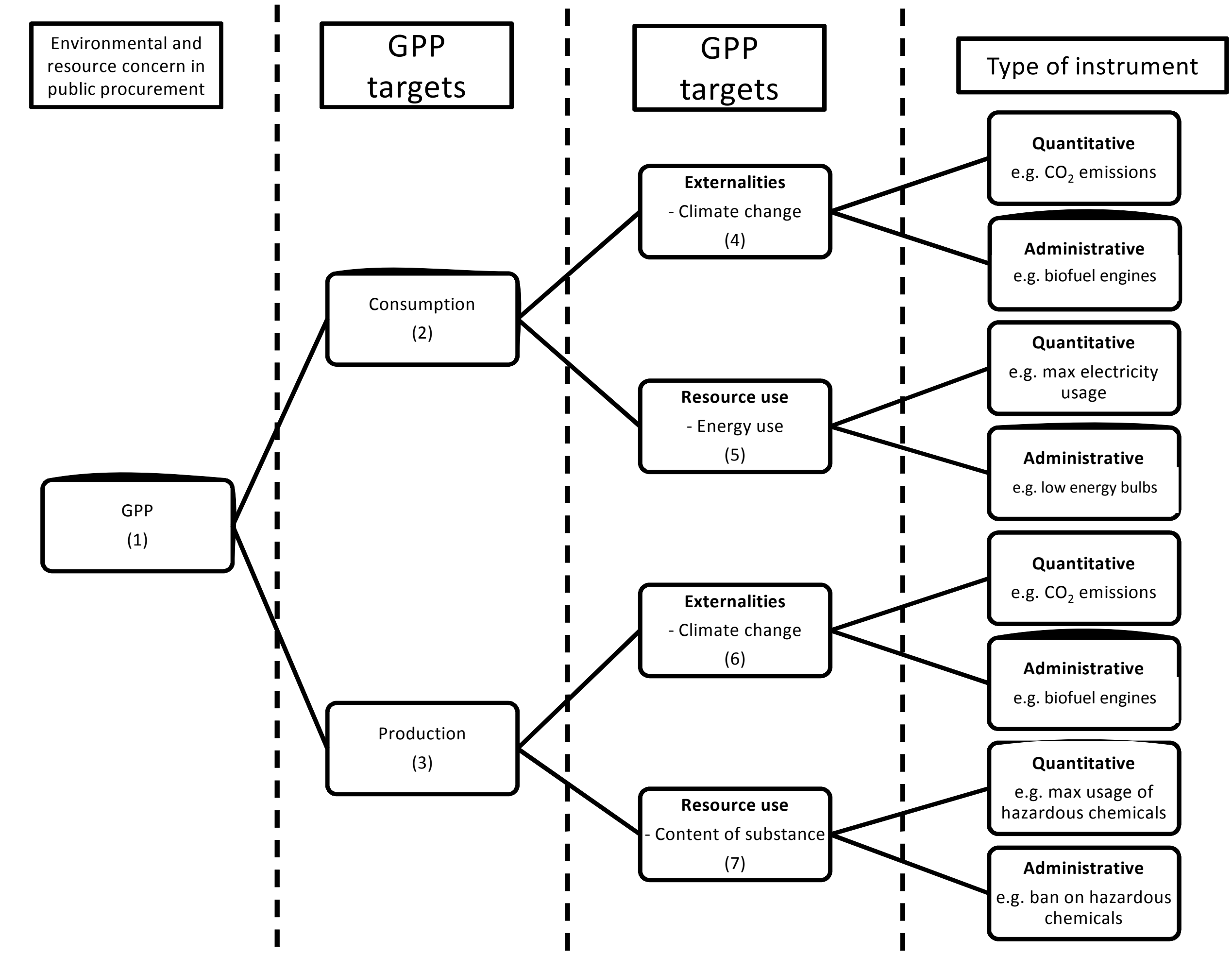

Fig. 1. Environmental concern in public procurement

Alternatively, the authorities can self-regulate their own operations (Box 5), by, e.g., procuring products that require less resource use, e.g., energy use. However, this is a pure cost minimization aspect that corresponds to LCC considerations, which should not be confused with internalizing externalities by using environmental policy instruments. Of course, less energy use would also likely contribute indirectly to less emission of carbon dioxide.

Contracting authorities can also focus environmental externalities from their own consumption (Box 4), e.g., by procuring biofuel vehicles and, as earlier mentioned, have also the option to practice whole-life-costing analyzes to account for total emissions related to the product.

Finally, authorities can implement criteria in purpose of, e.g., influencing potential suppliers to substitute environmental friendlier inputs (e.g. with less carbon content) for less environmental friendlier inputs in their production (Box 7).

Discussion and conclusions

GPP should not be considered as a cost-effective environmental policy instrument and, therefore, the cost-effectiveness argument should be used more carefully when advocating GPP. However, this does not necessarily mean that GPP should be categorically denied as a policy instrument.

As the political ambition in EU is to practice GPP extensively, there is an urgent need for further research on the topic of when to actually implement GPP. The peer-reviewed literature in economics on the subject of GPP and its prerequisites to work as an environmental policy instrument compared to alternative instruments is today virtually non-existent. For instance, does GPP as an environmental policy instrument generally satisfy environmental objectiveness? If not, do the principles of non-discrimination and equal treatment prevent GPP to work objective effectively? If not, what types of pollutants are suitable for GPP to address? Should GPP be practiced on markets of certain goods and services? Should GPP be practiced on markets where large-scale production is advantageous? To the best of our knowledge, this type of questions is still to be answered within the frame of welfare economics.

An important reflection is that our theoretical analysis establishes that GPP is cost-ineffective from a static point of view. However, there are indications that GPP is also inefficient in a dynamic perspective. Dynamic efficiency refers to policy instruments and their ability of spurring to cost-reducing technological development. Then, if GPP would be dynamically efficient in terms of leading to the development of greener technologies, it could outweigh the disadvantageous of being cost-ineffective in a static sense. However, as argued in this paper, GPP is to be seen as a command-and-control environmental policy instrument, implementing direct controls. The result in Milliman and Prince (1989) shows that direct controls give less incentives to promote technological development compared to economic instruments such as emission taxes and marketable permits. The result in Jung, Krutilla and Boyd (1996) shows a similar outcome. A hypothesis proposed is that as a per-unit emission tax rate continues to impose costs on suppliers even after they have adjusted to the tax rate it stimulates to cost-reducing technological development on continuous basis. A similar suggestion is made indirectly from a static analysis in Marron (1997) regarding the effects of procurement on development of green technologies: *"..., when available, other policies that encourage both the government and the private sector to increase purchases of green products should be more effective in promoting innovation* (p. 300)". Additionally, Porter and van der Linde (1995), discussing what is now thought of as the Porter hypothesis, stress the importance of governments avoiding administrative requirements such as technology specific ones: "*One useful change would be to alter the current practice of requiring suppliers in competitive bid processes for government projects to only bid with "proven" technologies, a practice sure to hinder innovation* (p. 112)."

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Appendix

Cost-effective emission control. The mathematical derivation of necessary conditions for cost-effective emission control, presented here, is based on the derivation presented by Tietenberg and Lewis (2009). The presentation concerns a general case of emissions, or pollutants, in the sense that it is valid for both uniformly mixing and non-uniformly mixing pollutants.

Assume a single receptor, *R*. In the case of a uniformly mixing pollutant emissions from all sources have the same impact on the receptor. For instance, independently of location, all sources of CO_2 emissions contribute equally to the concentration of greenhouse gases in the atmosphere; the atmosphere being the receptor in this case[1]. The policy objective would naturally address the pollutant concentration at the receptor, but suppliers' emissions are what actually can be targeted by the regulating authority. The relationship between supplier *i*'s emission, z_i, and its contribution to the pollutant concentration level at the receptor, CL_R, may be described as follows:

$$CL_R = \sum_{i=1}^{N} \alpha_i z_i + BC, \tag{A1}$$

where the supplier specific constant α_i is the transfer coefficient. Background pollutant concentration at the receptor is denoted *BC*. The *BC* concentration stems from natural emission sources and sources outside the region of policy control, e.g., other countries. Assume that the policy objective is to reduce the pollutant concentration level to CL_R^*, and that the authority's optimization problem then is to find the cost-effective level of control, ΔT_{iR}^*, for each source of emission. Explicitly, the cost minimizing problem corresponds to the Lagrangian expression as follows:

$$L = \sum_{i=1}^{N} CA_i\left(\Delta T_i\right) + \mu\left[\sum_{i=1}^{N} \alpha_i\left(T_i - \Delta T_i\right) + BC - CL_R^*\right], \tag{A2}$$

where $CA_i\left(\Delta T_i\right)$ is the cost of achieving the control level, ΔT_i. The Lagrange multiplier is denoted μ.

The first order conditions necessary for cost-effective emission reduction are

$$MCA_i - \mu\alpha_i = 0, \quad i = 1,\ldots,N, \tag{A3}$$

where the marginal cost of adjustment $MCA_i = \frac{\partial CA_i\left(\Delta T_i\right)}{\partial \Delta T_i}$ (the marginal cost of reducing the pollutant concentration at the receptor), and

$$\sum_{i=1}^{N} \alpha_i\left(T_i - \Delta T_i\right) + BC - CL_R^* = 0. \tag{A4}$$

[1] In the case of a given non-uniformly mixing pollutant all emission sources have not the same detrimental impact on the receptor. For instance, in the case of firms' emissions to a water stream, and the receptor being a delta located downstream, firms located upstream have less impact on the delta compared to firms located downstream close to the delta – this due to pollutants being diluted. Hence, the environmental damages caused by the downstream firms are larger and therefore they should meet more stringent environmental regulations compared to the firms upstream.

The solutions to these conditions give the $i = 1,\ldots,N$ optimized control variables, ΔT_i^*, and μ^*, which can be considered as the implicit cost, or shadow cost, of reducing the last unit of concentration. Welfare maximizing policies imply choosing environmental objective, CL^*_R, and pollution control, ΔT_i^* such that μ^* equals the society's marginal utility of the last unit of reduced concentration at the receptor.

If the pollutant is uniformly mixing all the N transfer coefficients are set to unity, i.e., $\alpha_i = 1$ (Tietenberg and Lewis, 2009, p. 388), and equation (A3) can be rewritten as:

$$MCA_i - \mu = 0, \quad i = 1,\ldots,N. \tag{A3'}$$

Clearly, for a cost-effective outcome, all N suppliers' marginal cost of adjustment must be equal to the marginal utility of the last reduced unit emission. Accordingly, $MCA_i = MCA_j, i \neq j,$ must be fulfilled. Baumol and Oates (1971, 1988) show that this outcome is achieved by imposing a per-unit tax on emissions corresponding to μ and, hence, the tax is being a cost-effective environmental policy instrument.

For GPP to be a cost-effective environmental policy instrument, environmental criteria must be specified individually among the potential suppliers such that the cost of adjustment for the last unit reduced emission equals μ for all suppliers. That is, if suppliers are heterogeneous in production and abatement technologies they should not meet exactly identical requirements in terms of environmental criteria in the call for tender.