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# Why Local Governments Set Climate Targets: Effects of City Size and Political Costs

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# Abstract

Cities increasingly address climate change, e.g. by pledging city-level emission reduction targets. This is puzzling for the provision of a global public good: what are city governments' reasons for doing so, and do pledges actually translate into emission reductions? Empirical studies have found a set of common factors which relate to these questions, but also mixed evidence. What is still pending is a theoretical framework to explain those findings and gaps. This paper thus develops a theoretical public choice model. It features economies of scale and distinguishes urban reduction targets from actual emission reductions. The model is able to explain the presence of targets and public good provision, yet only under specified conditions. It is also able to support some stylized facts from the empirical literature, e.g. on the effect of city size, and resolves some mixed evidence as special cases. Larger cities chose more ambitious targets if marginal net benefits of mitigation rise with city size—if they set targets at all. Whether target setting is more likely for larger cities depends on the city type. Two types are obtained. The first type reduces more emissions than a free-riding city. Those cities are more likely to set a target when they are larger. However, they miss the self-chosen target. Cities of the second type reach their target, but mitigate less than a free-riding city. A third type does not exist. With its special cases, the model can thus guide further empirical and theoretical work.

**Keywords** Local provision of public goods  $\cdot$  Political economy  $\cdot$  Voters  $\cdot$  Lobbyists  $\cdot$  Co-benefits  $\cdot$  Private costs of carbon

JEL Classification  $~Q54\cdot Q58\cdot D72$ 

# **1** Introduction

More and more cities worldwide set targets to mitigate greenhouse gas emissions within their jurisdiction, even if these cities are in countries which do not have effective climate targets or policies in place (e.g. Andonova et al. 2017; Rivas et al. 2021). When we consider mitigation as a contribution to a global public good, we might expect that

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such targets are just cheap talk or green washing—and have no effect. Yet, there are some indications that target-setting cities indeed achieve emission reductions (Hsu et al. 2020). One common finding in empirical studies on urban climate governance so far is that larger cities are more active in this field (e.g. Andonova et al. 2017; Steffen et al. 2019). This theoretical paper studies possible explanations for the existence and effectiveness of city-level climate targets, and how they depend on city size (and other parameters), by scrutinizing two kinds of mechanisms: Economies of scale, and local public choice mechanisms which might induce local governments to consider more than local opportunity costs. While the paper primarily aims to contribute to the theory of urban climate governance, it also aims at deducing hypotheses which are empirically testable. Since essential data is still notoriously difficult to collect, e.g. whether cities actually reduce emissions, it requires careful consideration to ensure that a model also makes predictions about better observable variables.

By the end of 2022, more than 1000 cities from all over the world report their greenhouse gas emissions to the Carbon Disclosure Project (CDP), following a common standard (Protocol 2015). Examples for cities with ambitious emission reduction targets are Atlanta, Bogotá, Copenhagen or Istanbul; and counterexamples, according to CDP at the time of writing, are Beijing, Kinshasa, Nagoya or Valetta (see also Roggero et al. 2023a). The greenhouse gas reduction potential of existing measures or targets of non-national government actors is estimated at 1.2 GtCO2e/year or even larger (Graichen et al. 2017; Roelfsema et al. 2018; Kuramochi et al. 2020). For a representative sample of 885 European cities, Reckien et al. (2018) showed that more than 2/3 had a climate mitigation plan in place as of 2017, and about 1/4 an adaptation plan. So-called transnational municipal networks (TMN) like the Global Covenant of Mayors for Climate and Energy (GCoM), or the International Council of Local Environmental Initiatives (ICLEI) prominently make visible urban climate action (e.g. Castán-Broto and Westman 2020; Berrueta and van der Heijden 2021). At the time of writing, GCoM has more than 13,000 member cities, in total representing more than 1 billion people, and pledging annual emission reductions by 3.8 GtCO2e until 2050. Although members of TMNs tend to be concentrated in the North, they have global coverage (Bansard et al. 2017). On the other hand, Kona et al. (2018) find that only 17% of GCoM signatories submitted monitoring reports prior to 2017. Later, among more than 5000 municipalities that submitted a "Sustainable Energy Action Plan" to GCoM, about 1/3 credibly monitor their emissions (Rivas et al. 2021).

Environmental economics has a long tradition of studying local emissions and abatement, but less so on greenhouse gas emissions. Many studies concentrate on the effects and valuation of local pollutants and resources (e.g. Deng and Mendelsohn 2021; Isphording and Pestel 2021; Klaiber and Morawetz 2021; Xia et al. 2022). To address local pollution, others publications study specific policy instruments and measures (e.g. Akbulut-Yuksel and Boulatoff 2021; Rivera 2021; Baranzini et al. 2021; Dijkstra 2022). Usually, they do not take a (positive) public choice perspective (but see Thomas and Zaporozhets 2017; Wu and Cao 2021; Fageda et al. 2022). A set of papers expands the monocentric city model of urban economics to study determinants of urban (greenhouse gas) emissions, partially in relation to environmental policy instruments (e.g. Borck and Brueckner 2018; Regnier and Legras 2018; Kyriakopoulou and Picard 2021; Marz and Goetzke 2022). Other cityrelated studies focus on adaptation to climate impacts (e.g. Ando et al. 2020; Bierl and Marz 2023). Local support of renewables as a mitigation measure is studied by Steffen et al. (2019). I'm yet not aware of environmental economics papers which aim to explain cities' contributions to global public goods, or to address the question under which conditions local governments set (or achieve) climate mitigation targets.

The model in this paper should be read against the background of existing empirical studies, mostly undertaken in geography and political science (see van der Heijden 2019; Castán-Broto and Westman 2020, for excellent overviews). Some of them are case studies, or focus on small sets of cities (e.g. Dale et al. 2020), while others investigate larger samples (e.g. Pablo-Romero et al. 2015; Heikkinen et al. 2020; Krause et al. 2021). They address different research questions, for example to find factors which drive climate adaptation plans or mitigation plans (e.g. Eisenack and Roggero 2022; Klein et al. 2018), or the interaction of both types of plans in cities (e.g. Lee et al. 2020). Other studies aim to explain participation in TMNs (e.g. Lee 2019), or emission reductions (e.g. Hsu et al. 2020; Roggero et al. 2023a).

This research produced some stylized facts and identified areas with mixed evidence. If we want to develop theoretical models of urban climate governance, those should be able to reproduce this evidence. To be clear, I use the term "ambition" in this paragraph to broadly mean different things ranging from policy input to policy outcome: an early adoption of climate plans, higher emission reduction targets, more support of mitigation or adaptation, and so on (the model below will work with a precise definition). With this broad understanding, the literature can support the finding that (1) cities with a larger capacity (proxied by high GDP/capita, city size, or other indicators) are more ambitious, possibly in a hill-shaped pattern (e.g. Lee 2013; Araos et al. 2016; Andonova et al. 2017; Reckien et al. 2018; Steffen et al. 2019; Krause et al. 2021). (2) Higher vulnerability or stronger exposure to impacts may lead to more ambition, but some studies show only a weak relation or the opposite (see Zahran et al. 2008; Wang 2012; Reckien et al. 2015; Kalafatis 2018; Boussalis et al. 2018). It is intuitive for mitigation, that the relation is weak at most, but not for adaptation. (3) It might also be that ambition is not so much driven by direct costs and benefits, but more by the preferences of the local constituency. Local voters or the local industry might push their governments for less or more climate action. Yet, while existing studies for the US mostly show a clear effect of local voter preferences, findings on the presence of the fossil fuel industry or on the more general role of voter preferences are inconclusive (e.g. Zahran et al. 2008; Wang 2012; Pablo-Romero et al. 2015; Kalafatis 2018; Boussalis et al. 2018; Armstrong 2019; Hui et al. 2019, ). (4) Larger co-benefits of mitigation, i.e. if climate action has additional local benefits or selective incentives, e.g. by reducing local air pollution or traffic congestion, might be one reason for city governments to be more ambitious. Empirical studies, however, show that this is not necessarily the case (e.g. Krause 2011; Lee and van de Meene 2013; Pablo-Romero et al. 2015; Rashidi and Patt 2018; Dale et al. 2020; Roggero et al. 2023b). (5) Ambition of cities and national governments can be complements or substitutes (Reckien et al. 2015; Heidrich et al. 2016; Reckien et al. 2018; Woodruff and Stults 2016; Domorenok 2019). Some national policies now oblige cities to make plans, but with mixed outcomes (e.g. Reckien et al. 2018).

One suggestion to resolve this mixed evidence is to classify cities into different types. Mechanisms at work are seemingly different depending on the kind of city (Berrueta and van der Heijden 2021; Eisenack and Roggero 2022). What is also lacking are economic explanations for the discussed and other possible factors, or even of city types. While the factors (1–3) will be center stage in this paper, I will show that some model parameters also address factors (4–5).

I do so by setting up a public choice model: It assumes a local government which does not necessarily maximize city welfare. In addition to the costs and benefits from mitigation, which scale with city size, the model considers the political preferences of its constituency (e.g. expressed by voters or influential lobbyists). Furthermore, the model distinguishes the climate targets that a government may set (as frequently observed nowadays) from the emission reductions that are actually achieved (and are more difficult to observe)—thereby admitting a possible mismatch between both. Targets are assumed to be set in response to demands from the constituency. The local government obtains a political value from setting an (un)ambitious target, which is balanced against the costs and benefits from actual mitigation, and future political costs if the target is not met. It is assumed that targets are only set if the political gains are large enough.

This setup admits to derive the conditions under which political preferences can explain the presence of climate targets, whether targets are achieved, and to study the comparative statics profiles with respect to various parameters related to the above factors. The effect of vulnerability on the target level is positive, for instance, and the effect of abatement costs is negative. Further effects of some parameters differ among the derived city types. In particular, larger cites are more likely to set a target if their marginal net benefits of mitigation rise, *and* if the target would lead them to contribute more mitigation than a free-riding city. It is shown that targets are not achieved by cities where the constituency demands more mitigation than a free-riding city would provide. Cities which contribute more to the global public good are exactly those which set less ambitious targets than their constituency prefers.

The next section starts with a simple expository model, which is extended to the full model in Sect. 3 to include climate targets and political costs (the Appendix considers an alternative model). I then compare the results for the identified city types, and discuss implications for empirical research in Sect. 4. Section 5 concludes.

# 2 Expository Model

I start with an expository model to make the puzzle of why cities should contribute to a global public good explicit. It also starts introducing notation. Further, the model leads to a first observation of the role of city size. In the subsequent sections, the model will be extended by considering emission reduction targets in addition to actual emission reductions (mitigation), and to accommodate additional mechanisms.

Consider a single city with size *s* which decides about mitigation *m*, its contribution to a global public good. City-level welfare is expressed by W = B - C, where *B* denotes the benefits from mitigation (reduced climate damages and other possible benefits), and *C* the mitigation costs. Mitigation *m* is measured as abatement relative to city size (e.g. a share of certain baseline emissions), so that total mitigation from within the

s > 0	City size
$q \ge 0$	City mitigation level (emissions abatement)
$q_0 > 0$	Total mitigation of all actors outside the city
$m \ge 0$	City mitigation (emissions abatement relative to size)
$\delta > 0$	Private cost of carbon (relative to size)
$\kappa > 0$	Cost parameter for abatement costs ("abatement costs" for short)
$t \ge 0$	City mitigation target (relative to size)

Table 1 Basic variables

city is q = sm, which adds to mitigation outside the city  $q_0$ . In the expository model, I assume a linear benefit function, and the following cost function (see Table 1 for notation; assumptions are generalized subsequently):

$$B = s\delta \cdot (q + q_0) = s^2 \delta m + s\delta q_0, \tag{1}$$

$$C = \frac{\kappa}{2s}q^2 = 1/2\,s\kappa m^2.\tag{2}$$

Cities which are more vulnerable to climate change have higher *private* costs of carbon  $\delta$ . Cities with higher abatement costs have a higher value of  $\kappa$ . Benefits, expressed as function of total mitigation q, scale linearly with s, because larger cities suffer more climate damages in total (think of  $\delta$ , applying to each inhabitant).

Marginal mitigation costs  $dC/dq = q\kappa/s$ , however, decrease with *s*. This assumption (which will be generalized below) is important for the remainder of the paper. It is reasonable when assuming that larger cities dispose over a larger set of abatement options, and is also used for abatement cost curves of countries (e.g. Criqui et al. 1999; Eisenack 2012; Hagen and Schneider 2021). The intuition becomes stronger when considering the marginal costs as a merit order curve. Each block of the marginal cost curve can be considered as one option. If one option is *s* times more available, each block becomes *s* times broader on the *q* axis, i.e. the marginal cost curve of a larger city is flatter by stretching the *q* axis by a larger factor *s*.

In this section I assume that the city selects mitigation  $m = m^e$  which maximizes citylevel welfare W, i.e. I assume a city which does not care about actors outside the city, but internalises all climate change impacts for actors in the city. The subscript "e" refers to the expository model solution, but can be also understood as the solution that keeps all climate damages outside the city externalized. Thus, it is convenient to call  $m^e$  the mitigation level of a free-riding city. The first-order condition is sufficient, so that one obtains

$$m^e = s \frac{\delta}{\kappa}.$$
 (3)

Intuitively, cities with higher private costs of carbon or with lower abatement costs mitigate more. Interestingly, (relative) mitigation rises with size. For the city mitigation level, there is the quadratic relation  $q^e = s^2 \delta/\kappa$ . This is driven by larger cities both enjoying more benefits and lower marginal costs.

At this stage, one might wonder whether findings on national-level climate policies (e.g. on international environmental agreements, Barrett 1994; Marrouch and Chaudhuri 2015; Hagen and Eisenack 2019) can be carried over to the local level. Yet, there are some crucial differences between cities and countries. Cities are embedded in multi-level (national) systems, which leads to binding institutions for local governments, which can both constrain/guarantee their authority or provide/restrict incentives (e.g. Meya and Neetzow 2021; Coria et al. 2018). Cities are larger in number but smaller in size than countries, which might shift free-riding incentives (see Foucart and Wan 2018, for federal systems). Due to size and legal restrains from higher levels, mechanisms of lobbying and rent-seeking presumably work differently on the local level (Peterson 1981). Yet, although there are such constraints, local governments have some authority over climate-relevant policies like transport, spatial planning, building codes or waste management (Holian and Kahn 2015; Hooghe et al. 2016; Brolinson et al. 2023), and the right or obligation to set climate targets (Reckien et al. 2018), in many countries. The puzzle of the existence of city climate

targets might also be understood as private provision of public goods (Olson 1965; Bergstrom et al. 1986). This huge literature has identified mechanisms that enhance cooperation, but primarily for individuals (in particular in experiments), and not for governments (e.g. Chaudhuri 2011). The provision of public goods is also studied in fiscal or environmental federalism, for instance to characterize the efficient allocation of decision-making power over different levels of government, or deteriorating environmental standards due to inter-jurisdictional competition (e.g. Oates 2005; Kunce and Shogren 2005). Yet, I am not aware of economics literature that explains the provision of global public goods by local governments.

It is thus worth studying urban climate action in its own right, by expanding on the expository model. To provide a first idea of how the models in the paper might also be used to scrutinize the effects of more variables than abatement costs and private costs of carbon, consider a carbon price set by a national government: This could be captured by a mark-up on the value of  $\delta$ . Another example are climate policy co-benefits (see, e.g. Regnier and Legras 2018; Karlsson et al. 2020; Chan and Zhou 2021). If mitigation leads to other benefits for the city (e.g. better local air quality or energy savings), and if they depend linearly on *q*, this would be equivalent to increasing  $\delta$  for the considered city. If co-benefits would depend quadratically on *q*, it would be equivalent to a lower  $\kappa$ . So, intuitively, more cobenefits or a higher carbon price would raise mitigation.

Yet, without a carbon price, the private cost of carbon  $\delta$  must assumed to be quite low, even very large cities cannot be expected to contribute much to the global public good voluntarily. If we want to explain why some cities are actually mitigating, we need to add more mechanisms to the model. Furthermore, the model does not represent city mitigation targets *t*, although this is a policy now frequently observed in cities.

# 3 Full Model

The full model expands the expository one by joining a second decision variable: the possibility of the local government to set a mitigation target t before emissions are actually reduced. Naturally, efficient quantity instruments, for instance, are only possible if there are targets. There are likely further reasons why a target might matter. I study one in this section, while delegating an alternative model to Appendix B.

Here, I expand the city welfare function by a public choice perspective to represent the preferences of local governments. That city governments do not necessarily optimize the aggregated welfare of its citizens is reasonable in light of the agency problems and institutional constraints that citizens and their city governments face. Depending on a country's constitution, local governments are more or less accountable to their constituency. Voters or lobby groups might favour more or less ambitious local climate policies than would be rational for a free-riding city. All we need to assume here is that the local government has some degree of authority over urban climate governance (see Sect. 2).

Once a city mitigation target t is introduced from a public choice perspective, one can naturally compare t against mitigation m. There is no reason to generally assume that m = t. The model assumes that targets act as a kind of *commitment device* for the local government, which can gain by bringing m closer to t. But intuition and the expository model lend to the expectation that commonly m < t, i.e. that cities mitigate less than "promised". Yet, it also becomes a logical possibility that cities "overachieve" mitigation targets with m > t. The following shows, inter alia, when this is the case, and under which conditions local governments set targets at all.

#### 3.1 Model Structure with Targets as Commitment Device

Generalize mitigation benefits and costs B, C from the expository model, and assume the local government's maximand is:

$$W = V(t;\psi,\nu) - T(t) + B(m;s,\delta) - C(m;s,\kappa) - S(m,t;\sigma).$$
<sup>(4)</sup>

See Table 2 for assumptions on the functions and parameters. I first explain the functions and then the parameters. The political value for the city government from target setting is denoted by V. The value might be due to awards or office rents if the city government meets it's constituency's political preferences for targets, or if higher institutional levels require or incentivize some target setting (e.g. national governments or the European Commission, cf. Reckien et al. 2018; Commission 2021; Eisenack and Roggero 2022). Citizens might demand for carbon policies (Holian and Kahn 2015). The political value might also stem from city reputation building, avoiding public unrest, effective civil society involvement, or private sector lobbying (see below for the parameters  $\psi$ , v). The model abstracts from different reasons that might all lead to the general assumptions.

Political costs *S* link the effect of the target *t* to achieved mitigation *m*, thus becoming the commitment device. How strong a deviation from the target is politically "punished" can depend, again, on various mechanisms. One might be the re-election probability of politicians that do not keep electoral promises but aim for sustained office rents (see, e.g. Klingelhöfer 2021). Not meeting targets can also be associated with a loss of reputation. Furthermore, targets can change private choices for long-lived investments. If targets are not enforced, assets of those who trust the targets might become stranded (see, e.g. Eisenack et al. 2021; Eisenack and Paschen 2022; Von Dulong et al. 2023), incentivizing their owners to lobby for achieving the targets (see below for parameter  $\sigma$ ).

The local government's transaction costs T stem from developing and setting a climate target. City-level emissions inventories are the basis for credible targets, but implementing them requires considerable expertise (Arioli et al. 2020). Certified climate plans usually require dedicated staff and audits, sometimes membership fees (Heikkinen et al. 2020). An industry of consultancies is already emerging. The C40 network finances a secretariat with more than 180 staff (Steffen et al. 2019). Cities can thus be reluctant to join transnational

$\overline{B, B_m > 0, B_{mm}} = 0$	$B_s, B_\delta > 0, B_{ms}, B_{m\delta} > 0,$	Mitigation benefits
$C, C_m, C_{mm} > 0$	$C_s, C_\kappa > 0, C_{ms}, C_{m\kappa} > 0$	Mitigation costs
V	$V_t \doteq \psi - t, V_{tt} < 0$	Political value of targets
$\psi \ge 0$	$V_{t\psi} > 0$	Target bliss-point
$\nu \ge 0$	$V_{\nu} \doteq V$	Target importance
$S, S_{mm}, S_{tt} > 0$	$S_m \doteq m - t, S_t \doteq t - m, S_{mt} < 0$	Political costs of targets
$\sigma \ge 0$	$S_{\sigma} > 0,$	Achievement importance
T(t)	$T' \ge 0, T'' \ge 0$	Transaction costs of targets
$a = (C_{mm} + S_{mm})(S_{tt} - V_t)$	$(+T'') - S_{mt}^2 > 0$	Strict convexity

Table 2 Variables, general monotonicity and convexity assumptions

Subscripts denote derivatives. Throughout this paper, = denotes equivalence in signs

municipal networks (Bansard et al. 2017). Pre-contractual transaction costs are caused by administrative processes (e.g. to overcome silo thinking, Oseland 2019), or to garner political acceptance through internal or external city diplomacy (Acuto and Rayner 2016; Roggero et al. 2023b, 2024).

Political value V and transaction costs T can be thought to be short-term, while the mitigation cost and benefits B, C and the political costs S occur in the long run (discounted to present value). If the local government sets a target (today), it commits to achieving this to some degree, because it might suffer from higher political costs if the target is not met sufficiently (tomorrow). The strength of this commitment device depends, of course, on the structure of S. If there was no function like S, there would be no reason for governments to achieve any "promised" mitigation targets. For clarity, these assumptions isolate the mitigation costs and benefits as much as possible from the political costs and benefits. One might argue that climate damages also influence political benefits, but this would make the model more complicated without additional insight: It already assumes that the government weighs damages with political costs. If there would be a strong interaction between mitigation and preferences of voters or lobbyists, they can be considered part of S.

The general monotonicity and convexity assumptions and the interpretation of the parameters  $\psi$ , v,  $\sigma$  are as follows (see Table 2). Benefits B are kept linear in m, which is not a strong assumption in this context, since a single city (even a megacity) is marginal compared to the global scale of the problem. A convex cost function C which becomes more steep for rising  $\kappa$  is common. With  $C_{ms} > 0$  it is assumed that the cost-reducing effect of more mitigation options being available in larger cities is weaker when marginal costs rise. The political value  $V(t;\psi, v)$  is a single-peaked concave function in t which rises up to a bliss-point at  $t = \psi$ , and decreases for higher targets. With this assumption, the political value depends on the relative target t, and not on the total city mitigation level q which is aimed at. The parameter  $\psi$  thus expresses the target that is taken into account by the decision-maker when contemplating the preferences of her constituency. If the assumptions on V would be justified by a probabilistic voting model (e.g. Persson and Tabellini 2000),  $\psi$  might represent the target most preferred by the median voter. A high value of  $\psi$  means that, by whatever political mechanism, the local government has reason to set more ambitious targets. The political value is further characterized by v, which is larger if the singlepeaked function has a steeper slope. If the target deviates from  $\psi$ , a larger v means that the local government loses more value. The sign of  $V_{tw}$  simply expresses that the peak is shifted with  $\psi$ . The political value can be positive, but can also take negative values, e.g. to represent sanctions for certain target levels.

The political costs  $S(m, t; \sigma)$  are single-dipped: they are convex in *m* and reach their minimum if the target is achieved at m = t. Again, political costs are driven by relative mitigation *m*, and not the mitigation level *q*. The parameter  $\sigma$  expresses the scale of the political costs: they rise if  $\sigma$  becomes larger. Thus, high values of *v* and  $\sigma$  express a situation where the local government cares more about local climate policy, which can be due to their local voters, national-level obligations or incentives imposed on the local government, or vested interests. The last assumption a > 0 guarantees existence and uniqueness of the optimum of Eq. (4).

In this way, the model's advantage is that the assumptions are open to different interpretations which can help adjust for different research objectives and empirical designs. For example, one can focus on different political mechanisms (e.g. driven by voters, lobbyists, bureaucrats or combinations thereof). If one is interested in the effects of national or regional carbon prices, she can check which function would represent this in the best way, e.g. a linear shift of the mitigation benefits *B*. Before the city government maximizes W with respect to (t, m), consider a further decision: whether to set a mitigation target at all. This leads to the following staged decision, which will be solved backwards.

- 1 The local governments decides on setting a target or not.
- 2a If there is no target, the city decides about mitigation  $m = m^{\circ}$  under the assumption that  $V, S, T \equiv 0$ .
- 2b If there is a target, the government decides on the target level and mitigation  $(t^*, m^*)$ .

Stage 1 is relevant if there are not sufficient gains from target setting to justify the transaction costs *T* (see below). If this is the case, stage 2a assumes a behaviour like a free-riding city from the expository model (with the generalized cost function *C*). This assumption is not as strong as it appears, since it does not exclude the possibility of political costs due to not setting a target: The value  $V(t;\psi, v)$  can be understood as the government's forgone benefits from not setting a target *t*. Furthermore, the assumption still admits to consider sanctions (e.g. if not following a national government's program) or disadvantages if a city is not mitigating much (which could be represented by modifying *B* or *C*). This staged decision structure particularly plays out if there are "fixed" transaction costs which even occur when setting a quite non-ambitious target (T(t) > 0 for *t* close to zero), while we have a discontinuity with T = 0 if the local government does not set a target at all. However, if setting a target in stage 2b leads to higher *W* for the government than the stage 2a equilibrium, we can assume that the local government decides to set a target in stage 1.

**Stage 2a** If the local government decides not to set a target, the maximand becomes  $W^{\circ}(m) = B(m) - C(m)$ . Here and in the following, I skip the parameters as arguments of the functions in order to ease notation. The optimum  $m^{\circ}$  is characterized by  $B_m = C_m$  (equivalent to the free-riding city  $m^{\circ} = m^e$  according to Eq. (3) in the expository model). The comparative statics are:

$$\frac{dm^{\circ}}{ds} = \frac{B_{ms} - C_{ms}}{C_{mm}} \doteq B_{ms} - C_{ms},\tag{5}$$

$$\frac{dm^{\circ}}{d\delta} = \frac{B_{m\delta}}{C_{mm}} > 0, \tag{6}$$

$$\frac{dm^{\circ}}{d\kappa} = \frac{-C_{m\kappa}}{C_{mm}} < 0.$$
<sup>(7)</sup>

The effect of  $\delta$ ,  $\kappa$  is qualitatively the same as for the expository model. Larger cities, however, only mitigate more if  $B_{ms} - C_{ms} > 0$ , i.e. if net benefits of mitigation rise with city size. If a city's net benefits of mitigation decrease if it grows, the expression would be negative. Since the sign of this expression (which is ambiguous from the assumptions) will be important throughout the analysis, conveniently denote it by the shortcut

$$w := B_{ms} - C_{ms} \lessgtr 0. \tag{8}$$

**Stage 2b** If the local government decides to set a target, the first-order conditions for (m, t) are

$$B_m(m^*) = C_m(m^*) + S_m(m^*, t^*),$$
(9)

$$V_t(t^*) = S_t(m^*, t^*) + T'(t^*).$$
<sup>(10)</sup>

In general, one cannot show that the solution  $m^*$ ,  $t^*$  is non-negative. In the following I assume that this is the case.

When further studying the solutions of stage 2b, it is interesting to compare whether the presence of targets leads to more mitigation than if targets are absent. Thus, I subsequently call cities with  $m^{\circ} < m^*$  **contributor cities** (ctr), because they contribute more to the public good than a free-riding city ( $m^{\circ} = m^e$ ) would do. Second, I call cities which "promise" lower targets  $t^* < m^*$  than they actually achieve **understatement cities** (ust). Note that cities that do not set a target in stage 1 can also be classified as one of the two types, by considering what they would do if they were somehow forced to set one. The following comparative statics for stage 2b, and further (arguably paradoxical) results for understatement and contributor cities can be determined:

**Proposition 1** If the local government sets a target (with an inner solution), then (i) the stage 2b comparative statics follow Table 3. In particular, size leads to more ambitious targets and to more mitigation if and only if w > 0. (ii) If the target t becomes more ambitious by some reason, there is also more mitigation m. (iii) Contributor cities are exactly characterized by  $m^{\circ} < m^{*} < t^{*}$ , which is equivalent to  $C^{\circ} < C^{*}$ , and to  $B_{m}^{*} < C_{m}^{*}$ . (iv) Understatement cities are exactly characterized by  $t^{*} < m^{*} < m^{\circ}$ , which is equivalent to  $C^{\circ} < C^{*}$ , and to  $C_{m}^{*} < B_{m}^{*}$ . (v) Except for cities with  $C^{*} = C^{\circ}$ , every city is either an understatement or a contributor city. (vi) All contributor cities respect  $t^{*} < \psi$ . Conversely,  $\psi < t^{*}$  is sufficient to have an understatement city.

The proof in Appendix A uses total differentiation and compares the mitigation, target and cost levels by turning back to the first-order conditions and exploiting the derived monotonicity and convexity properties.

The proposition states that, among those cities which have a target, the larger ones promise and achieve more—if a larger city has higher net benefits from mitigation. The political value and costs can be removed from this condition. Since size does not affect V, S, the "direct net benefits" B - C drive the effect. Higher private costs of carbon raise both targets and achieved mitigation. Since political value and costs are assumed to be independent from the damage suffered from climate change, the changes in B drive the

Table 3Comparative staticsof stage 2b for targets as a		$\frac{dm^*}{d\cdot}$	$\frac{dt^*}{d\cdot}$
commitment device	$\frac{d}{ds}$	$\frac{w(S_u - V_u + T'')}{a} \doteq w$	$-\frac{w}{a}S_{mt} \doteq w$
	$\frac{d}{d\delta}$	$\frac{B_{m\delta}(S_{tt}-V_{tt}+T'')}{a} > 0$	$-\frac{B_{m\delta}S_{mt}}{a} \doteq -S_{mt} > 0$
	$\frac{d}{d\kappa}$	$\frac{C_{m\kappa}(S_n - V_n + T'')}{-a} < 0$	$\frac{C_{mk}S_{mt}}{a} < 0$
	$\frac{d}{d\sigma}$	$\frac{S_{i\sigma}S_{mi} - S_{m\sigma}(S_{ii} - V_{ii} + T'')}{a} \leq 0$	$\frac{S_{m\sigma}S_{mt} - S_{t\sigma}(c_{mm} + S_{mm})}{a} \leq 0$
	$\frac{d}{d\psi}$ $d\cdot$	$-\frac{v_{ty}s_{mt}}{a} > 0$ $S_{mt}V_{ty} \div V$	$\frac{V_{tw}(C_{mm}+S_{mm})}{a} > 0$ $V_{tv}(C_{mm}+S_{mm}))  \cdot  V$
	dv	$-a = v_{tv}$	$a = v_{tv}$

picture. A similar intuition holds for higher mitigation costs: They unambiguously reduce both targets and mitigation.

Interestingly, if missing the target has higher political costs (high  $\sigma$ ), this can both support mitigation or backfire. The local government might anticipate being sanctioned for missing targets, thereby promising less ambitious targets, which would then lead to less mitigation. Also, the effect of a stronger target importance ( $\nu$ ) is ambiguous. If  $\nu$  raises the marginal political value, both target and mitigation will be higher, while the effect reverses otherwise. What is unique, however, is that target and mitigation are higher if the constituency's target bliss-point is larger: Preferences for more ambitious targets indeed convert into both promises and action. In particular, the model predicts that cities which chose targets above  $\psi$ , in turn achieve mitigation above their targets. For targets below  $\psi$  the same kind of statement cannot be made in general.

Moreover, cities which mitigate more than a free-riding city (ctr) are exactly those which mitigate less than stated in in their targets (see Fig. 1). In contrast, if a city government sets a higher target than its constituency prefers, it will indeed achieve this target (ust). However, this only happens when both target and mitigation are below the free-riding city level. In light of this paradoxical effect, Proposition 1 shows that there is no third possibility (except for the boundary case). This can be interpreted as follows. Cities are either of the kind where the constituency demands more mitigation than a free-riding city would supply, or where the constituency demands less mitigation. If the local government sets targets, it would choose them so that they deviate from the free-riding level in the direction which pleases its voters or lobbyists. This "pleasing effect" needs to be balanced with the mitigation costs and the political costs from making too extreme promises, so that mitigation is ultimately between target and the free-riding level. In short, understatement cities contribute *less* to the global public good. This should not be interpreted, due to the positive public-choice character of the model, that a city *should* chose an overambitious target in order to contribute to the public good. Instead, it predicts that exactly those cities which do not achieve their target mitigate more than free-riders. In other words, if the model is an appropriate representation of reality, we should not be disappointed if cities fail to meet self-selected targets.

**Stage 1** The city government may chose not to have a target if it anticipates in stage 1 that it obtains less with target  $(W^*)$  than without  $(W^\circ)$ . Denote the difference by  $\Delta := W^* - W^\circ = B(m^*) - C(m^*) + V(t^*) - S(m^*, t^*) - T(t^*) - B(m^\circ) + C(m^\circ)$ . Generally, the assumptions made so far do not imply a specific sign of  $\Delta$ . However, the comparative statics with respect to the various parameters are more clear. This indicates whether  $\Delta$  is more likely to be positive if a certain parameter is larger—so whether the likelihood of city to

**Fig. 1** Illustration of achieved mitigation, target, and bliss-point for a contributor city (arbitrary cost and benefit functions). To ease the presentation,  $t^*$  and  $\psi$  are somewhat imprecisely put on the mitigation axis. They are measured on the same scale as  $m^{\circ}, m^*$ . For an understatement city, the ordering of  $m^{\circ}, m^*, t^*$  would reverse



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set a target is higher or not. We obtain (see Appendix for the proof which uses the Envelope Theorem):

**Proposition 2** In stage 1, the gains from setting an optimal target depend on the parameters as given in Table 4.

Interestingly, higher private costs of carbon  $\delta$  do not necessarily make the presence of a climate target more likely—this is only the case for contributor cities. A higher target bliss-point  $\psi$  always makes target-setting more likely, while higher costs from failing the target  $\sigma$  makes it less attractive to set one. Contributor cities with higher abatement cost  $\kappa$  have less incentives to set a target, while the opposite holds for understatement cities. This is consistent because the target will be below what cities without a target will mitigate. In any case, the effect of  $\kappa$ works in the opposite direction of  $\delta$ . Among those cities with w > 0, larger contributor cities are more likely to have a target, which reverses for w < 0, and also reverses for the other city type. The effect of the target importance v depends on further assumptions on the political value V.

#### 3.2 Refined Model with Targets as Commitment Device

To resolve some ambiguities and to illustrate the findings, this section studies the following more specific version of the previous general model:

(Assumptions commitment) Assume a cost function of the form  $C(m) := \frac{\kappa}{s} \tilde{C}(sm)$ , based on an arbitrary twice differentiable function  $\tilde{C}(\cdot) > 0$  with  $\tilde{C}', \tilde{C}'' > 0$ . For the political value,  $V(t) := v\tilde{V}(t - \psi)$ , based on an arbitrary single-peaked, twice differentiable function  $\tilde{V}(\cdot)$  with  $\tilde{V}'' < 0$ . For an arbitrary argument *x*, I assume that  $\tilde{V}'(x) \doteq -x$ , so that the maximum is at zero. In the same way, take a twice differentiable convex function  $\tilde{S}(\cdot) \ge 0, \tilde{S}'' > 0$  with minimum  $\tilde{S}(0) = 0$ . For an arbitrary argument *x*,  $\tilde{S}'(x) \doteq x$ . I define  $S(m, t) := \sigma \tilde{S}(m - t)$ . Thus, there are no political costs if t = m, while those costs rise if mitigation deviates from the target in either direction. For the transaction costs I assume the simplest possible form  $T(t) = T_0 + \gamma t$ , where  $T_0$  denotes fixed transaction costs of setting targets. If there is no target, I again set  $T \equiv 0$ . The strict convexity condition can then be simplified to  $a = s\kappa \tilde{C}''(\sigma \tilde{S}'' - v \tilde{V}'') - \sigma v \tilde{S}'' \tilde{V}'' > 0$ , which is always satisfied for these assumptions. For *B*, I stick to the assumptions from the previous section.

The first-order conditions for stage 2a (to obtain  $m^{\circ}$ ) and stage 2b (for  $m^*, t^*$ ) can be explicitly written as

$$s^2\delta = \kappa \tilde{C}'(sm^\circ),\tag{11}$$

Table 4	Comparative static	s of
stage 1		

$\frac{d\Delta}{ds}$	$B_s(m^*) - C_s(m^*) - B_s(m^\circ) + C_s(m^\circ) \doteq (m^* - m^\circ)w$
$\frac{d\Delta}{d\delta}$	$B_{\delta}(m^*) - B_{\delta}(m^{\circ}) \doteq (m^* - m^{\circ})$
$\frac{d\Delta}{d\kappa}$	$-C_{\kappa}(m^*) + C_{\kappa}(m^{\circ}) \doteq -(m^* - m^{\circ})$
$\frac{d\Delta}{d\sigma}$	$-S_{\sigma}(m^*,t^*) < 0$
$\frac{d\Delta}{dv}$	$V_{\nu}(t^*) - V_{\nu}(0) \lessgtr 0$
$\frac{d\Delta}{d\psi}$	$V_{\psi}(t^*) - V_{\psi}(0) > 0$

$$s^2\delta = \kappa \tilde{C}'(sm^*) + \sigma \tilde{S}'(m^* - t^*), \tag{12}$$

$$\nu \tilde{V}'(t^* - \psi) = \gamma - \sigma \tilde{S}'(m^* - t^*).$$
(13)

They admit a further characterization of contributor and understatement cities, and the sign of the decisive term  $w(m) = B_{ms}(m) - C_{ms}(m)$ . I use the elasticity of marginal costs  $\eta = \tilde{C}'' \frac{sm}{\tilde{c}''} > 0$ , denoted by  $\eta^{\circ}$  if evaluated at the stage 2a equilibrium, and  $\eta^{*}$  for stage 2b.

**Proposition 3** If targets function as commitment device, (assumption commitment) holds, and interior optima exist in stage 2a, 2b, then  $w^{\circ} := w(m^{\circ}) \doteq 2 - \eta^{\circ}$ , and  $w^{*} := w(m^{*}) \doteq (2 - \eta^{*})C_{m}^{*} + 2S_{m}^{*}$ . Moreover,

- Contributor cities (i.e. with m° < m\* < t\*) are exactly those which satisfy one of the following equivalent conditions: (i) C̃'(sm°) − C̃'(sm\*) < 0; (ii) S̃' < 0; (iii) γ < vṼ'(t\* − ψ); (iv) s²δ < κC̃'(sm\*).</li>
- 2. Understatement cities are exactly those where all these inequalities are reversed.
- 3. All cities with  $\eta^* < 2$  and  $w^* < 0$  are contributor cities. All cities with  $\eta^* > 2$  and  $w^* > 0$  are understatement cities.
- 4. Equivalently, for all contributor cities with  $\eta^* > 2$ , also  $w^* < 0$  holds. For all understatement cities with  $\eta^* < 2$ , also  $w^* > 0$  holds.
- 5. Understatement cities chose  $t^* > \psi$  if and only if  $\sigma \tilde{S}' > \gamma$ . (Contributor cities always chose  $t^* < \psi$ , and respect  $\sigma \tilde{S}' < \gamma$ .)

Obviously, some results are more detailed than in Proposition 1. While it's already known that contributor cities only set targets below  $\psi$  (repeated for overview), now understatement cities only set targets above  $\psi$  if their (positive) marginal political costs are large enough (part 5). The Proposition has several implications. For instance, a city that has set a target is c.p. more likely a contributor city (part 1) if the (short-term) target importance is high, or if transaction costs are low. Those cities accept marginal mitigation costs above marginal benefits, which is c.p. more likely the case if the city has low private costs of carbon, is small, or has high mitigation costs.

Parts 3, 4 show that being an understatement or contributor city, and whether *w* is positive or negative, can occur in multiple combinations which are yet not completely independent from each other. Table 5 lists all possible cases according to Propositions 1 and 3 (excluding boundary cases). Some of the cases can arguably be excluded from the further discussion by considering the threshold for the marginal cost elasticity form parts 3, 4. If  $\tilde{C}'$  is isoelastic,  $\eta > 2$  would require the mitigation cost function to be steeper than a quadratic. As this is not quite common in the literature, it is worth concentrating on the shaded cases in Table 5.

If  $\eta < 2$ , only contributor cities can have w < 0: Among cities with a target, those which are less ambitious if the city is larger can only be contributor cities. Then also  $-S_m < (1 - \eta/2)C_m$ . The left side of the latter inequality is positive since the city does not achieve its target. Thus, cities where size is associated with lower targets are those with c.p. high abatement costs or where not achieving targets is associated with low political costs ( $\sigma$ ).

Whatever the sign of w, all contributor cities with targets (i.e. with  $m^{\circ} < m^{*} < t^{*} < \psi$ ) face transaction costs below the marginal target importance, so that they can afford

$\eta < 2$	type	$t^* < \psi$	w	further properties
yes	(ctr)	yes	(-)	$\left[ \int_{\sigma} \tilde{S}' < 0 < \gamma < \mu \tilde{V}' \right]$
yes	(ctr)	yes	(+)	
yes	(ust)	yes	(+)	$0 < \nu \tilde{V}', \sigma \tilde{S}' < \gamma$
yes	(ust)	no	(+)	$\nu \tilde{V}' < 0 < \gamma < \sigma \tilde{S}'$
no	(ctr)	yes	(-)	$\sigma \tilde{S}' < 0 < \gamma < \nu \tilde{V}'$
no	(ust)	yes	(-)	$\Big]_{0 < \mu \tilde{V}' \sigma \tilde{S}' < \gamma}$
no	(ust)	yes	(+)	
no	(ust)	no	(-)	$\Big]_{\mathcal{V}\tilde{\mathcal{V}}' < 0 < \gamma < \sigma \tilde{\mathcal{S}}'}$
no	(ust)	no	(+)	

Table 5 Overview of all possible cases for contributor (ctr) and understatement (ust) cities

ambition in this respect. If they would chose an even more ambitious target (in the extreme case above  $\psi$ ), however, they would suffer too much from failing it in terms of political costs *S*. Thus, mitigation is below the target because the political costs and value cannot overcompensate the mitigation costs and benefits. One might say that contributor cities with targets are characterized by an ambitious constituency with  $\psi > m^{\circ}$ . They chose a compromise between the high bliss-point for targets and the lower mitigation if they were a free-riding city. In this compromise, the target functions as a kind of stepping stone between preferences and action, which raises mitigation, yet in an imperfect way.

If  $v\tilde{V'} < 0 < \gamma < \sigma \tilde{S'}$  holds, we have an understatement city which sets targets at least more ambitious than its constituency wants (i.e.  $\psi < t^* < m^* < m^\circ$ ), a polar case compared to contributor cities. Again, the target can be considered as a stepping stone between preferences and action, yet in the other direction: The city's constituency prefers to have less mitigation than a free-riding city would do. However, Table 5 shows that there can also be understatement cities with  $t^* < \psi$  (if they have comparatively low marginal political costs, so that they are even less ambitious in light of the transaction costs).

Now turn to the comparative statics. Much follows from substituting (assumptions commitment) into into Tables 3, 4, where some signs have already been established. Further ambiguities can be resolved by making use of Proposition 3.

**Proposition 4** When (assumptions commitment) holds, the comparative statics follow Table 6 for stage 2b, and Table 7 for stage 1. If  $t^* < \psi$  (e.g. for contributor cities), then  $\frac{d\Delta}{dy} > 0$ . Stage 2a reads as follows:

$$\frac{dm^{\circ}}{ds} = \frac{2s\delta - \kappa m^{\circ}\tilde{C}''}{s\kappa\tilde{C}''} = \frac{2\delta}{\kappa\tilde{C}''} - \frac{m^{\circ}}{s} \doteq 2s\delta - \kappa m^{\circ}\tilde{C}'' = w,$$
$$\frac{dm^{\circ}}{d\delta} = \frac{s}{\kappa\tilde{C}''} > 0,$$
$$\frac{dm^{\circ}}{d\kappa} = -\frac{\tilde{C}'}{s\kappa\tilde{C}''} < 0.$$

<b>ble 6</b> Comparative statics stage 2b (with assumption		$\frac{dm^*}{d\cdot}$	$\frac{dt^*}{d\cdot}$
mmitment)	$\frac{d\cdot}{ds}$ $\frac{d\cdot}{d\delta}$ $\frac{d\cdot}{d\kappa}$ $\frac{d\cdot}{d\sigma}$ $\frac{d\cdot}{d\psi}$ $\frac{d\cdot}{d\psi}$ $\frac{d\cdot}{d\psi}$	$\begin{aligned} \frac{(2s\delta-\kappa m^*\tilde{C}'')(\sigma\tilde{S}''-\nu\tilde{V}'')}{a} &\doteq w\\ s^2\frac{\sigma\tilde{S}''-\nu\tilde{V}''}{a} > 0\\ -\frac{\sigma\tilde{S}''-\nu\tilde{V}''}{a}\tilde{C}' < 0\\ \frac{v}{a}\tilde{V}''\tilde{S}' &\doteq -\tilde{S}' &\doteq -(m^*-t^*)\\ -\frac{v\sigma}{a}\tilde{V}''\tilde{S}'' > 0\\ \frac{\sigma}{a}\tilde{S}''\tilde{V}' &\doteq \psi - t^* \end{aligned}$	$\frac{2s\delta - \kappa m^* \tilde{C}''}{a} \sigma \tilde{S}'' \doteq w$ $s^2 \frac{\sigma \tilde{S}''}{a} > 0$ $-\sigma \frac{\tilde{S}''}{a} \tilde{C}' < 0$ $s \frac{\kappa}{a} \tilde{C}'' \tilde{S}' \doteq \tilde{S}' \doteq m^* - t^*$ $-\frac{v \tilde{v}''}{a} (s \kappa \tilde{C}'' + \sigma \tilde{S}'') > 0$ $\frac{s \kappa \tilde{C}'' + \sigma \tilde{S}''}{a} \tilde{V}' \doteq \psi - t^*$
hla 7 Comparative statics			

 Table 7
 Comparative statics

 of stage 1 with (assumptions commitment)

Ta of co

$\frac{d\Delta}{ds}$	$2s\delta(m^* - m^\circ) + \frac{1}{s}(C^* - C^\circ) + \frac{1}{s}(m^\circ C_m^\circ - m^* C_m^*) \doteq (m^* - m^\circ)w$
$\frac{d\Delta}{d\delta}$	$s^{2}(m^{*} - m^{\circ}) \doteq (m^{*} - m^{\circ}) \doteq (t^{*} - m^{*})$
$\frac{d\Delta}{d\kappa}$	$\frac{1}{s}(\tilde{C}^{\circ}-\tilde{C}^{*})\doteq-(m^{*}-m^{\circ})\doteq-(t^{*}-m^{*})$
$\frac{d\Delta}{d\sigma}$	$-\tilde{S}^* < 0$
$\frac{d\Delta}{dv}$	$\tilde{V}(t^* - \psi) - \tilde{V}(-\psi) \lessgtr 0$
$\frac{d\Delta}{dw}$	$\nu(\tilde{V}'(-\psi) - \tilde{V}'(t^* - \psi)) > 0$

Table 8 Comparative statics summary for targets as commitment device (COM)

case	w	type	$t^* < \psi$	$\frac{d\Delta}{ds}$	$\frac{d\Delta}{d\delta}$	$\frac{d\Delta}{d\kappa}$	$\frac{dt^*}{ds}$	$\frac{dt^*}{d\delta}$	$\frac{dt^*}{d\kappa}$	$\frac{dt^*}{d\sigma}$	$\frac{dt^*}{d\nu}$
(COM.1)	(+)	(ctr)	yes	(+)	(+)	(–)	(+)	(+)	(-)	(–)	(+)
(COM.2a)	(+)	(ust)	yes	(-)	(-)	(+)	(+)	(+)	()	(+)	(+)
(COM.2b)	(+)	(ust)	no	(–)	(–)	(+)	(+)	(+)	(-)	(+)	(–)
(COM.3)	(-)	(ctr)	both	(-)	(+)	(-)	(-)	(+)	(-)	(-)	(+)
(COM.4)	(-)	(ust)		(+)	(-)	(+)	(-)	(+)	(-)	(+)	(?)

Case (COM.2) is split in two subcases depending on  $t^* \leq \psi$ . Also (COM.4) can be split to resolve the last ambiguity, but the case is only possible if  $\eta > 2$ , which may be unlikely (thus not shaded). For (COM.3), the relation between target bliss-point and target does not matter. Note that (COM.1) is only possible if  $\eta < 2$ 

By comparing with the tables from the general model, the ambiguity of target importance v and achievement importance  $\sigma$  in stage 2b is mostly resolved: For contributor cities, a higher target importance leads to both more ambitious targets and more mitigation. These cities also mitigate more if the achievement importance is stronger. Yet, in anticipation of these additional political costs they set less ambitious targets. For understatement cities, the effect of stronger achievement importance reverses: they admit higher targets and mitigate less in order to bring both together more closely, thus reducing political costs. Also the effect of target importance reverses. When the constituency cares more about the (low) target level, those more cautious city governments promise and mitigate less in order to obtain higher political net benefits. In order to prepare the next section, see Table 8 for a summary of some main results. The table emphasizes the effects on the presence  $\Delta$  and level of targets *t*, as these comparative statics are arguably more easily observed empirically than the effect on mitigation *m*. It becomes apparent that the cases have quite different comparative statics profiles (except for  $dt^*/d\delta$ ,  $dt^*/d\kappa$ ). The case (COM.1) describes contributor cities where the marginal net benefits of mitigation rise with size. Those cities always promise less ambitious targets than their constituency prefers. For contributor cities with decreasing marginal net benefits (COM.3), cities might also promise more, but this does not affect the direction in which the presence and ambition of targets change. The reasonable understatement cities can promise less (COM.2a) or more (COM.2b) than the bliss-point, but this difference only affects the comparative statics with respect to target importance.

## 4 Discussion

Now compare the deduced implications of the different cases (see Table 8). Cells where the cases make different predictions might be one reason why previous empirical studies show mixed results. Further empirical studies might be able to discriminate between the derived cases and test the model assumptions leading to these cases. I concentrate the discussion on the likelihood of having a target ( $\Delta$ ) and the mitigation target ( $t^*$ ). For both the presence and ambition of plans, large data sets are increasingly becoming available (e.g. Reckien et al. 2018; Hsu et al. 2020; Rivas et al. 2021; Moran et al. 2022). As possible drivers, consider city size *s*, mitigation costs  $\kappa$ , and  $\delta$ . The latter might be proxied by vulnerability indicators (e.g. Tapia et al. 2017). For cities in low-lying coastal areas, or which are badly adapted to climate change impacts, the private costs of carbon can expected to be higher. The city-level mitigation costs parameter  $\kappa$  might be estimated by downscaling country-level or sectoral abatement costs curves to the specific economic structure of cities, or in the bottom-up way by collecting and computing abatement options. Different proxies for city size, e.g. measured by population, area or GDP, are well available (e.g. Eurostat 2020; OECD 2020).

For all cases, higher social costs of carbon imply more ambitious targets. There are yet cases where  $\delta$  makes the presence of targets less likely, but this applies only to understatement cities with w > 0. Abatement costs  $\kappa$  can be either conducive or detrimental for the presence of targets, but always decrease their level. Consistently across all cases, the sign of  $w = B_{ms} - C_{ms}$  is important for the effect of city size on setting climate targets. However, among the  $\eta < 2$  cases, the common observations that larger cities more likely set targets can only be supported for contributor cities if w > 0. Further testable implications can be derived. As an example, consider it empirically robust that large cities more frequently have climate targets (see Sect. 1). Then the cases COM.2a, COM.2b and COM.3 are ruled out. Within the model, only case COM.1 or COM.4 apply. Among those cities, it might be that the higher- $\delta$  ones have no target (COM.4). If this is the case, those cities need to be of the w < 0 kind (or can be characterized as understatement cities, e.g. by using at least one of the equivalent criteria from Proposition 3). This entails a mitigation cost elasticity  $\eta$ larger than two. This can be tested empirically with city-level data on abatement costs. In addition, whatever the effect of vulnerability,  $d\Delta/ds > 0$  implies the prediction that w < 0only appears in conjunction with  $\eta < 2$ . Several other empirical strategies can be developed from Table 8.

So far, I concentrated on variables which might be observed more easily. The model yet also captures further variables, some of which might be proxied with empirical data, in order to test the model implications summarized in Tables 6 and 7. Political target importance v might be measured by variables which correlate with the general politisation of a city's citizens (e.g. education, voter turnout), or by variables about the importance of environmental issues (e.g. from opinion polls, environmental awareness studies, vote shares of green parties, cf. Bierl et al. 2024). If climate referenda have occurred, we obtain information about the bliss point  $\psi$ , and sentiments in journalistic sources might indicate the sign of  $(t - \psi)$ . Information about achievement importance might be obtained from public surveys, and arguably do not differ much between climate and other policy fields. Explicitly determining the sign of w will not be straightforward, since (in the refined model)  $w^* = 2\delta s - \kappa m^* \tilde{C}''$  depends on (future) mitigation  $m^*$ , which is still difficult to observe. Yet, particularly small or not very vulnerable (small  $s\delta$ ) cities should be of the w < 0 kind. Furthermore, recall from Sect. 2, that the formal properties of the parameters  $\delta$ ,  $\kappa$  allow for further interpretations, some of which are addressed in the empirical literature (e.g. co-benefits or national policies). Co-benefits from improving on air pollution in cities are assessed in several studies. The different cases might thus explain the mixed empirical findings on co-benefits, for instance (Sect. 1). Although measuring the ambition of national climate policies is not straightforward, data or indicators on those are available (e.g. Germanwatch 2020; Wendling et al. 2020). In addition, all cases predict that the level of city climate targets (where present) is a complement to a national carbon price (which raises  $\delta$ )—data on which is well documented. The partially mixed evidence on vulnerability, co-benefits and national-level incentives for the presence of plans thus breaks down to different cases.

It can be expected that empirical research will likely qualify some of the model implications. If empirical findings do not align with the model results, we might consider other core assumptions than climate targets functioning as a commitment device. Appendix B thus studies an alternative model where targets function as a cost-saving device. This model partially leads to the same comparative statics results, but also to some other cases (see Appendix B.3 for a detailed comparison). For instance, it turns out that the parameter w appears again but plays another role. If marginal benefits rise more strongly with size than marginal costs, then larger cities are always more likely to set a target. Future empirical analyses might admit discriminating among such models.

# 5 Conclusions

The analysis started from the theoretical puzzle of why city governments might set local climate targets (and engage in mitigation), although they face a global public goods problem. This was contrasted with the state of the empirical literature that shows that many cities indeed set climate targets and possibly reduce greenhouse gas emissions. However, some theoretically reasonable factors which might explain target setting are not empirically confirmed so far. In contrast, some arguably non-obvious factors, like city size, seem to play an important role. The paper particularly addresses whether economics of scale and local public choice mechanisms can explain the presence of urban climate targets and action. It develops a theoretical model in order to explain the state of the empirical literature and to make predictions which can be validated against forthcoming data. Particularly, I explore the possibility that targets are set due to political gains of local governments (the public choice model with targets as "commitment device"; the Appendix also studies an alternative model where target setting reduces mitigation costs).

The public choice model is able to explain the presence of urban climate action under certain conditions. It particularly shows that we need to distinguish, among those cities that set mitigation targets, between understatement and contributor cities—*tertium non datur*. Both types can be characterized in several equivalent ways. Understatement cities mitigate more than they "promise" to their constituency when setting targets, but mitigate less than a city without climate targets. Contributor cities, in contrast, mitigate more than cities without a target. Interestingly, the latter cities' targets are below the bliss-point of their political constituency, and they do not reach the own target. Furthermore, the likelihood of setting a climate target can increase or decrease with vulnerability (depending on the derived conditions). Across all cases, more vulnerable cities set more ambitious targets, if they chose to have targets at all.

The previous results are mostly driven by the political costs and benefits. Since also economies of scale are introduced in the mitigation cost function, several effects do not scale linearly with city size. Generally, the effect of city size on the presence and ambition of targets is ambiguous. Yet, if size raises the marginal net benefits of mitigation, ambition rises with contributor cities' size. The effect of higher mitigation costs for the target level and for achieved mitigation is negative (these intuitive results do not hold for the alternative model). The effect of vulnerability or the private cost of carbon is ambiguous for the presence of targets, and the different cases can be characterized.

Since the proposed model abstracts from the concrete political processes, the analysis comes with some limits. In particular, one might conceive further mechanisms than those studied here. The paper can provide a starting point for micro-foundations (Sect. 3 discusses some directions focusing on electoral accountability or on lobbying in the presence of specific investments), possibly in combination with further empirical research. In principle, the characterizations and predictions of the model can be tested quantitatively (see Sect. 4). Since political preferences or private costs of carbon presumably differ between cities, not all cities on the world can be expected to follow the same case. More generally, the model indicates that cities need to be distinguished by type in order to identify clear-cut drivers of urban climate governance, a finding in line with other studies, which might be addressed with novel approaches like archetype analysis (Berrueta and van der Heijden 2021; Eisenack and Roggero 2022; Piemontese et al. 2022).

Since several model parameters can be reasonably interpreted in different ways, the model admits some policy conclusions, in particular how (inter)national institutions might influence city-level choices. For instance, the private cost of carbon can be raised with a carbon price, which would increase the ambition of targets. Mandates or subsidies for cities could raise target importance or the bliss point. The former induces only contributor cities to become more ambitious so such policies should be targeted. The latter makes target-setting more likely for both city types. Policies can also raise achievement importance, e.g. through accountability mechanisms or sanctions. This can backfire: Fewer cities will set targets, but at least those contributor cities which still set targets mitigate more.

The paper also contributes to the more general literature on environmental policy targets. To my knowledge, nearly all environmental economics papers on policy instruments start from the premise that targets are met (see Chiappinelli and May 2022, for one exception). This makes sense if one aims to determine optimal policies, or if policy instruments like an emissions trading system are explicitly designed to meet an emission target. In political practice, however, environmental policy targets are frequently agreed upon before the policy instruments to achieve them are chosen and adopted. The continued policy process might then lead to instruments that ultimately do not achieve the targets. While a possible mismatch between targets and their achievement has been noted in some papers on urban climate governance (e.g. Kona et al. 2018; Hsu et al. 2020; Roggero et al. 2023a), I think the present paper is one of the first to provide a more general theoretical entry-point to study under which conditions environmental policy targets are reached and to which degree.

Although puzzling, the existence of urban climate governance is a real trend which should not be ignored by environmental economics. The empirical literature so far indicates that not all urban climate plans are cheap talk or greenwashing, enforcing the call to study polycentric climate governance (Ostrom 2012; Cole 2015). However, templates for economic research on the conditions under which local governments contribute to global public goods are needed. I hope that the suggested approach, which does not depict local governments as welfare maximizers, helps towards this end. Expanding this theoretical research and using it to guide novel empirical studies can lead to the identification of drivers for successful city-level climate action, thereby characterizing how local governments can take their share in solving global problems. More generally, such research would explore the pitfalls and promises of the "think globally—act locally" mantra in a precise way.

# Appendix: Proofs

#### Proof of proposition 1

**Proof** For statement (i), the comparative statics can be directly computed by total differentiation of both first-order conditions, and subsequent simplification.

Statement (ii) follows from differentiating by *t* the identity  $0 \equiv B_m(\bar{m}(t)) = C_m(\bar{m}(t)) + S_m(\bar{m}(t), t^*)$ , with  $\bar{m}(t)$  obtained from Eq. (9), with  $\bar{m}'(t) = -\frac{S_{mt}}{C_{mm}+S_{mm}} > 0$ .

For statement (iii), the cost relation  $C^{\circ} < C^*$  directly follows from the definition of contributor cities  $(m^{\circ} < m^*)$  and  $C_{mm} > 0$ . For the rest of this statement, first recall that the first-order conditions state that  $C_m(m^{\circ}) - B_m(m^{\circ}) = 0$ , and  $C_m(m^*) - B_m(m^*) = -S_m(m^*, t^*)$ . Also note that  $\frac{d}{dm}(C_m(m) - B_m(m)) = C_{mm} > 0$ . With this inequality and the general assumptions (Table 2), a city is a contributor city  $(m^{\circ} < m^*)$  if and only if  $0 = C_m(m^{\circ}) - B_m(m^{\circ}) < C_m(m^*) - B_m(m^*) = -S_m(m^*, t^*) \doteq t^* - m^*$ , so that  $m^{\circ} < m^* < t^*$ . Statements (iv) and (v) then follow by contraposition.

The implications in statement (vi) are obtained by considering Eq. (10), the first-order condition for  $t^*$ . For a contributor city,  $t^* - m^* > 0$  by (iii), so that  $S_t > 0$ . Since also  $T' \ge 0$ , the first-order condition implies  $V_t > 0$ . By the properties of V, this implies  $t^* < \psi$ . The second implication again follows by contraposition.

#### Proof of Proposition 2

**Proof** Employ the envelope theorem for the derivatives of  $\Delta$ . With s, for instance,  $\frac{d\Delta}{ds} = W_s^* - W_s^\circ = B_s(m^*) - C_s(m^*) + V_s(t^*) - S_s(m^*, t^*) - T_s(t^*) - B_s(m^\circ) + C_s(m^\circ)$ . Evaluating and simplifying for all parameters yields the Table. The sign  $d\Delta/ds$  (and for  $\delta, \kappa$ ) can be alternatively expressed because  $\frac{d}{dm}(B_s(m) - C_s(m)) = w$ . For  $\psi$ , the derivative follows from  $t^* > 0$  (by assumption) and  $V_{tw} > 0$ .

#### **Proof of Proposition 3**

**Proof** To establish the sign of w, use (assumptions commitment) to express

$$w = B_{ms} - C_{ms} = 2\frac{B_m}{s} - \kappa m\eta \frac{\tilde{C}'}{sm} \doteq 2B_m - \kappa \eta \tilde{C}'(sm) = 2B_m - \eta C_m.$$
(14)

When evaluated at  $m^{\circ}$ , then  $B_m = C_m > 0$ , so that  $B_{ms} - C_{ms} \doteq 2 - \eta^{\circ}$ . At  $m^*$ , the first-order condition yields

$$w = B_{ms} - C_{ms} \doteq 2B_m(m^*) - \eta^* C_m(m^*)$$
(15)

$$= 2(C_m(m^*) + S_m(m^*, t^*)) - \eta^* C_m(m^*) = (2 - \eta^*)C_m^* + 2S_m^*.$$
 (16)

Now turn to part 1 and 2. Obtain (ii) by using Proposition 1 and noting that  $S_m \doteq m^* - t^*$ . Since  $\tilde{C}'' > 0$ , (i) is also implied by Proposition 1. Combining the first-order conditions yields

$$\kappa(\tilde{C}'(sm^\circ) - \tilde{C}'(sm^*)) = \sigma \tilde{S}'(m^* - t^*) = \gamma - \nu \tilde{V}'(t^* - \psi), \tag{17}$$

which is positive for understatement cities, and negative for contributor cities. Both cities types can be further characterized by inferring from Proposition 1 that the contributor cities are exactly those with  $V_t > T'$ , and exactly those with  $B_m^* < C_m^*$  (which is equivalent to  $m^* < m^\circ$ ).

Part 2 directly follows by Proposition 1 because there is no third kind of cities except the boundary case.

Part 3 further exploits Eq. (14) to obtain the following sufficient conditions for being a contributor or understatement city. If  $\eta^* < 2$  and  $w^* < 0$ , then  $0 > w^* \doteq B_m^* - \frac{\eta^*}{2}C_m^* > B_m^* - C_m^*$ , implying a contributor city. If  $\eta^* > 2$  and  $w^* > 0$ , then  $0 < w^* \doteq B_m^* - \frac{\eta^*}{2}C_m^* < B_m^* - C_m^*$ , so an understatement city. Part 4 is equivalent to part 3.

The last part is already shown in Proposition 1 for contributor cities. For understatement cities,  $\psi - t^* \doteq v \tilde{V}' = \gamma - \sigma \tilde{S}'$ , so that  $t^* < \psi$  iff  $\tilde{S}' < \gamma / \sigma$ .

#### Proof of Proposition 4

**Proof** Most are straightforward substitutions, simplifications, using previous results. The implication for  $t^* < \psi$  can be derived geometrically.

#### Appendix: Alternative Model

The paper's main model assumes that the main role of targets is political. Yet, other mechanisms might be drivers of target setting and their achievement. If other mechanisms can be justified theoretically, it would be interesting to check whether they would imply

qualitatively different results. One possibility could be targets which act as a *cost-saving device*, i.e. they might serve to reduce abatement costs. One reason for saving costs can be credible targets (with associated policy instruments) which incentivize long-term investments in assets (e.g. renewables, insulated buildings) which ease emission reductions, while without such targets, investors might not be willing to take such risk, thereby missing mitigation opportunities. Furthermore, ambitious policy targets might spur innovation (Ambec et al. 2013). In addition, public targets might also help to solve coordination dilemmas in the city, thereby reducing mitigation costs: some abatement options involve local network externalities (e.g. in the transport sector), so that multiple actors taking them into account can reduce costs. Different public administration departments might need to detail out mitigation plans (before implementing them), ideally in a way that fits to the plans of other related departments (e.g. the introduction of low emission zones in relation to re-allocating parking space and public transport).

#### Model Structure with Targets as Cost-Saving Device

With targets as a cost-saving device (and ignoring political incentives like in the other model), one can assume that the city government maximizes (with respect to t, m):

$$W = B(m;s,\delta) - C(m,t;s,\kappa) - T(t).$$
(18)

The benefit function *B* is of the same kind a before, while the cost function *C* also depends on the target *t* (i.e. the target saves costs). As before, *T* denotes the transaction cost of developing and setting public climate targets. The general monotonicity and convexity assumptions are given in Table 9. The last assumption a > 0 guarantees existence and uniqueness of the optimum of Eq. (18). Below, Appendix B.2 introduces a refined model version. The decision structure is as before. In Stage 1, the local government decides to set a target if and only if this leads to a larger maximand *W* than if  $t, T \equiv 0$ . In Stage 2a

 $B(m) \ge 0$ Mitigation benefits  $B_m > 0, B_{mm} = 0$ Linear  $B_s, B_{\delta} > 0$ Large and vulnerable cities benefit more ...  $B_{ms}, B_{m\delta} > 0$ ...also in terms of marginal benefits  $C(m, t) \ge 0$ Mitigation costs  $C_m,C_{mm}>0$ Costs convex in m  $C_t < 0, C_t > 0$ Targets reduce costs diminishingly  $C_{mt} < 0$ Targets reduce marginal costs  $C_{\kappa}, C_{m\kappa} > 0$ κ rises costs and marginal costs  $C_{s}, C_{ms} > 0$ Larger cities have higher (marginal) costs  $C_{t\kappa} < 0$ More effective targets in costly cities  $C_{ts} < 0$ More effective targets in large cities T(t) > 0Transaction costs  $T' \ge 0, T'' \ge 0$ More ambitious target is costly  $a := C_{mm}(C_{tt} + T'') - C_{mt}^2 > 0$ Strict convexity

 Table 9 General assumptions for targets as cost-saving device

(without a target), the city decides on mitigation  $m^\circ$ , while in Stage 2b (with a target), the government decides on the target level and mitigation  $t^*$ ,  $m^*$ .

**Stage 2a:** If the government has decided not to set a target, the optimal  $m^{\circ}$  is obtained from maximizing B(m) - C(m, 0) with respect to m. This is simply the expository model, now with the more general assumptions, so that  $m^{\circ} = m^{e}$ . The first-order condition  $B_{m}(m^{\circ}) = C_{m}(m^{\circ}, 0)$  yields the same comparative statics as for targets as commitment device.

**Stage 2b:** If the government has decided to set a target, the first order conditions for  $(m^*, t^*)$  are  $B_m(m^*) = C_m(m^*, t^*)$ ,  $T'(t^*) = -C_t(m^*, t^*)$ , which are sufficient due to the general convexity assumptions. From now on assume that both variables are positive in the optimum. The comparative statics of the solution are:

$$\frac{dm^*}{ds} = \frac{C_{ts}C_{mt} + w(C_{tt} + T'')}{a} \le 0,$$
(19)

$$\frac{dt^*}{ds} = -\frac{wC_{mt} + C_{mm}C_{ts}}{a} \leq 0,$$
(20)

$$\frac{dm^*}{d\delta} = \frac{B_{m\delta}(C_{tt} + T'')}{a} > 0, \tag{21}$$

$$\frac{dt^*}{d\delta} = -\frac{C_{mt}B_{m\delta}}{a} > 0, \qquad (22)$$

$$\frac{dm^*}{d\kappa} = \frac{C_{t\kappa}C_{mt} - C_{m\kappa}(C_{tt} + T'')}{a} \leq 0,$$
(23)

$$\frac{dt^*}{d\kappa} = \frac{C_{m\kappa}C_{mt} - C_{mm}C_{t\kappa}}{a} \leq 0.$$
(24)

At least one sufficient condition for a unique sign of Eqs. (19) and (20) can be identified. It is also possible to compare mitigation between Stage 2a and 2b:

**Proposition 5** If targets are a cost-saving device and the local government decides to have a target, the comparative statics of the target  $t^*$  and mitigation  $m^*$  follows Eqs. (19)–(24). If w > 0, then both Eqs. (19) and (20) are positive, and  $dm^\circ/ds > 0$ . For mitigation,  $m^* \ge m^\circ$  always holds.

**Proof** Comparative statics are obtained by total differentiation and the assumptions in Table 9. The implication of w > 0 is easily verified. For  $m^* \ge m^\circ$ , define the function  $\bar{m}(t)$  by  $B_m(\bar{m}(t)) - C_m(\bar{m}(t), t) \equiv 0$ . The optimum in the absence of a target is expressed as  $m^\circ = \bar{m}(0)$ , and  $m^* = \bar{m}(t^*)$ . By differentiating,  $B_{mm}\bar{m}'(t) - C_{mm}\bar{m}'(t) - C_{mt} = 0$ , so that  $\bar{m}' = -\frac{C_{mt}}{C_{mm}} > 0$ . Since  $t^*$  cannot be negative by definition,  $m^* = \bar{m}(t^*) \ge \bar{m}(0) = m^\circ$ .

Note that the assumptions for targets as a cost-saving device do not require a specific metric for the target (e.g. targets for relative or absolute emission reductions, or abatement technologies) since they just represent a (political) activity which reduces costs.

Thus, it does not make sense to determine whether targets are achieved or not for this model version.

**Stage 1:** When comparing a situation with target  $W^* = B(m^*) - C(m^*, t^*) - T(t^*)$  and without target  $W^\circ = B(m^\circ) - C(m^\circ, 0)$ , the properties of the difference in government's benefits  $\Delta = W^* - W^\circ$  are as follows:

**Proposition 6** When targets are a cost-saving device, the gain from setting them depend on the parameters as follows. If w > 0, then  $d\Delta/ds > 0$ .

$$\frac{d\Delta}{ds} = (B_s(m^*) - C_s(m^*, t^*)) - (B_s(m^\circ) - C_s(m^\circ, 0)) \le 0,$$
(25)

$$\frac{d\Delta}{d\delta} = B_{\delta}(m^*) - B_{\delta}(m^\circ) \ge 0, \tag{26}$$

$$\frac{d\Delta}{d\kappa} = C_{\kappa}(m^{\circ}, 0) - C_{\kappa}(m^{*}, t^{*}) \leq 0.$$
(27)

**Proof** For any kind of parameter, e.g. s, the envelope theorem guarantees

$$\frac{d\Delta}{ds} = W_s(m^*, t^*) - W_s^{\circ}(m^{\circ}) = B_s(m^*) - C_s(m^*, t^*) - T_s(t^*) - B_s(m^{\circ}) + C_s(m^{\circ}, 0) + T_s(0),$$
(28)

which is simplified here for  $s, \delta, \kappa$ . The second inequality holds due to Proposition 5 and  $B_{\delta m} > 0$ .

For the first inequality, employ  $\bar{m}$  from Proposition 5 again, and note that  $B_s(m^*) - C_s(m^*, t^*) = NB(t^*) := B_s(\bar{m}(t^*)) - C_s(\bar{m}(t^*), t^*)$ , and  $B_s(m^\circ) - C_s(m^\circ, 0) = NB(0)$ . Then,  $\frac{NB}{dt} = B_{sm}\bar{m}' - C_{sm}\bar{m}' - C_{st} = (B_{ms} - C_{ms})\bar{m}' - C_{st}$ . The convexity assumptions and  $t^* > 0$  then show that w > 0 is a sufficient (but not necessary) condition for  $NB(t^*) > NB(0)$ . Thus, Eq. (25) is positive.

#### **Refined Model with Targets as Cost-Saving Device**

(Assumptions cost-saving) Assume a cost function of the form  $C = \frac{\kappa}{s}f(t)\tilde{C}(sm)$ , where the functions  $f, \tilde{C}$  satisfy: f > 0, f(0) = 1, f' < 0, f'' > 0, and  $\tilde{C}, \tilde{C}', \tilde{C}'' > 0$ . This form captures a multiplicative cost-saving effect from targets through the function f. Transaction costs T and benefits B are the same as for the commitment device model. Thus,  $a = C_{mn}C_{tt} - C_{mt}^2 = \kappa^2 (f\tilde{C}f''\tilde{C}'' - (f'\tilde{C}')^2)$ . Since a > 0 is needed, the choice of  $f, \tilde{C}$  is more restricted. Define  $u := \tilde{C}\tilde{C}'' - \tilde{C}'^2$  and  $v := ff'' - f'^2$ . Then,  $u, v > 0 \Rightarrow a > 0$ , and  $u, v < 0 \Rightarrow a < 0$ , and  $u \cdot v < 0 \Rightarrow a \leq 0$ . The decision problem is not well-posed if both u, v are negative. By using the cost elasticity  $\epsilon := \tilde{C}'(sm)\frac{sm}{C} > 0$ , it can be noted that  $sm\tilde{C}' - \tilde{C} = \epsilon\tilde{C} - \tilde{C} = (\epsilon - 1)\tilde{C}$ . Thus, iff the cost elasticity of  $\tilde{C}$  is always above unity, both  $C_s, C_{ts}$  are uniquely positive.

**Stage 2a** If there is no target, the first-order condition is  $s^2\delta = \kappa \tilde{C}'(sm^\circ)$ , with the comparative statics

$$\frac{dm^{\circ}}{ds} = \frac{2s\delta - \kappa m^{\circ}\tilde{C}''}{s\kappa\tilde{C}''},\tag{29}$$

$$\frac{dm^{\circ}}{d\delta} = \frac{s}{\kappa \tilde{C}^{\prime\prime}} > 0, \tag{30}$$

$$\frac{dm^{\circ}}{d\kappa} = -\frac{\tilde{C}'}{s\kappa\tilde{C}''} < 0.$$
(31)

From Appendix B.1,  $w = B_{ms} - C_{ms} > 0$  is sufficient for  $\frac{dm^{\circ}}{ds} > 0$ . For the comparative statics in the optimum,  $C_m = B_m$ , so Eq. (14) can be written as follows. If the marginal costs have an elasticity of 2 or less (in the optimum), then—in the absence of a target—increasing size makes optimal mitigation larger:

$$w \doteq 2B_m - \eta C_m = (2 - \eta)B_m. \tag{32}$$

**Stage 2b** The first-order conditions for (m, t) are  $s^2 \delta = \kappa f(t^*) \tilde{C}'(sm^*)$ ,  $\gamma = \frac{\kappa}{s} f'(t^*) \tilde{C}(sm^*)$ , and the comparative statics for *s*,  $\delta$ ,  $\kappa$  evaluate to

$$\frac{dm^*}{ds} = -\frac{m^*}{s} + \frac{\kappa}{s^2 a} \tilde{C} \left( 2s^2 \delta f^{\prime\prime} - \kappa f^{\prime 2} \tilde{C}^{\prime} \right), \tag{33}$$

$$\frac{dt^*}{ds} = \frac{\kappa}{sa} f' \left( \kappa f \tilde{C} \tilde{C}'' - 2s^2 \delta \tilde{C}' \right), \tag{34}$$

$$\frac{dm^*}{d\delta} = \frac{s\kappa}{a} f''\tilde{C} > 0, \tag{35}$$

$$\frac{dt^*}{d\delta} = -\frac{s^2\kappa}{a}f'\tilde{C}' > 0, \tag{36}$$

$$\frac{dm^*}{d\kappa} = \frac{\kappa}{sa} \tilde{C} \tilde{C}' (f'^2 - ff'') \doteq -v, \qquad (37)$$

$$\frac{dt^*}{d\kappa} = \frac{\kappa}{a} ff'(\tilde{C}'^2 - \tilde{C}\tilde{C}'') \doteq u.$$
(38)

**Proposition 7** Suppose (assumptions cost-saving) hold. Then  $\frac{dm^{\circ}}{d\delta}, \frac{dm^{*}}{d\delta}, \frac{dt^{*}}{d\delta} > 0$ , and  $\frac{dm^{\circ}}{d\kappa} < 0$ . If  $\eta < 2$ , then  $w, \frac{dm^{\circ}}{ds}, \frac{dm^{*}}{ds}, \frac{dt^{*}}{ds} > 0$ . It holds that  $\frac{dm^{*}}{d\kappa} < 0$  iff v > 0 (which is always the case if u < 0). Furthermore,  $\frac{dt^{*}}{d\kappa} < 0$  iff u < 0. Finally, u < 0 iff  $C^{\circ} < C^{*}$ .

**Proof** The comparative statics have already been shown. With applying Eq. (32) for stage 2,  $\eta < 2$  guarantees w > 0. This is, due to Proposition 5, a sufficient condition for  $\frac{dm^*}{ds}, \frac{dt^*}{ds} > 0$ . For a well-posed problem, u < 0 requires v > 0, so that  $\frac{dm^*}{d\kappa} < 0$ . For the cost comparison, use  $\bar{m}(t)$  from Proposition 5, and observe

$$\frac{d}{dt}C(\bar{m}(t),t) = C_m\bar{m}' + C_t = -C_m\frac{C_{mt}}{C_{mm}} + C_t$$
(39)

$$= -\kappa f \tilde{C}' \frac{\kappa f' \tilde{C}'}{s \kappa f \tilde{C}''} + \frac{\kappa}{s} f' \tilde{C}$$
(40)

$$=\frac{\kappa}{s}f'\left(-\tilde{C}'\frac{\tilde{C}'}{\tilde{C}''}+\tilde{C}\right)\doteq\left(\frac{\tilde{C}'^2-\tilde{C}\tilde{C}''}{\tilde{C}''}\right).$$
(41)

Thus (since  $t^* > 0$ ) if  $-u = \tilde{C}'^2 - \tilde{C}\tilde{C}'' > 0$ , then  $C^* = C(\bar{m}(t^*), t^*) > C(\bar{m}(0), 0) = C^\circ$ .

Stage 1 For the decision whether to set a target, the derivatives of  $\Delta$  from Proposition 6 evaluate to

$$\frac{d\Delta}{ds} = 2s\delta(m^* - m^\circ) + \frac{1}{s}(m^\circ C_m^\circ - m^* C_m^* - C^\circ + C^*) \le 0,$$
(42)

$$\frac{d\Delta}{d\delta} = B_{\delta}(m^*) - B_{\delta}(m^\circ) = s^2(m^* - m^\circ) \ge 0, \tag{43}$$

$$\frac{d\Delta}{d\kappa} = \frac{1}{s}(\tilde{C}^{\circ} - f^*\tilde{C}^*) = \frac{1}{\kappa}(C^{\circ} - C^*).$$
(44)

**Proposition 8** Suppose (assumptions cost-saving) hold. Then, the likelihood of having a target changes according to Eqs. (42)–(44). If  $\eta < 2$ , then Eq. (42) becomes positive. Equation (44) is negative iff u < 0.

**Proof** The comparative statics are straightforward by substituting the derivatives into the results from Proposition 6. If  $\eta < 2$ , Proposition 7 shows that w > 0, which implies Eq. (42) to be positive by Proposition 6. Due to Proposition 7, the last expression is positive iff u > 0.

Table 10 summarizes the main results. For Stage 1, w > 0 is sufficient for larger cities being more likely to set a target (Proposition 6), and for the refined model  $\eta < 2$  is also

 Table 10
 Comparative statics summary for targets as a cost-saving device (refined model)

case	w	u	$\frac{d\Delta}{ds}$	$\frac{d\Delta}{d\delta}$	$\frac{d\Delta}{d\kappa}$	$\frac{dt^*}{ds}$	$\frac{dt^*}{d\delta}$	$\frac{dt^*}{d\kappa}$	$\frac{dm^*}{ds}$	$\frac{dm^*}{d\delta}$	$\frac{dm^*}{d\kappa}$
(CST.1)	(+)	(-)	(+)	(+)	(-)	(+)	(+)	(-)	(+)	(+)	(-)
(CST.2)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	(+)	$-\operatorname{sgn}(v)$
(CST.3)	(-)	(-)	(?)	(+)	(-)	(?)	(+)	(-)	(?)	(+)	(-)
(CST.4)	(-)	(+)	(?)	(+)	(+)	(?)	(+)	(+)	(?)	(+)	$-\operatorname{sgn}(v)$

The specifications of u, v depend on the mitigation costs C (both can be negative or positive in principle). If  $\eta < 2$ , only the shaded cases are possible

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sufficient (Proposition 8). See main text why  $\eta < 2$  might be more appropriate. Mitigation costs  $\kappa$  have an ambiguous effect for setting a target (depending on the sign of *u*). The effect of  $\delta$  is unique (non-negative), as in the commitment-device model. It can thus be said that (by also using Proposition 5)—if the hypothesis holds that climate targets are primarily a cost-saving device—cities with higher  $\delta$  are more likely to set such a target, and if they indeed set it, it is more ambitious and they mitigate more.

Also for Stage 2b, w > 0 is a sufficient condition for larger cities mitigating more, but not a necessary one. It is also possible that with  $B_{ms} < C_{ms}$ , some target setting cities still have a positive effect of size, while this would not be the case if they do not set a target. In the refined model a cost elasticity  $\eta < 2$  is also a sufficient condition for larger cities abating more (Proposition 7). Cost-saving targets generally increase mitigation (Proposition 5). This is intuitive, since targets always reduce mitigation costs and (besides transaction costs) have no other disadvantages in this section's model.

If the cases CST.1, CST.2 are more relevant, then the cost-saving model is consistent with the empirical finding that larger cities tend to have climate plans more frequently. For the common class of isoelastic cost functions  $\tilde{C}(q) = \kappa q^{\epsilon}$ , for instance, u < 0 (and the boundary case u = 0 follows from an exponential cost function). Then, as shown above, only v > 0 is possible. In those cases, cities with higher mitigation costs  $\kappa$  chose lower targets and reduce emissions less. In such as setting, cities with targets have higher mitigation expenditures. In a nutshell, the model with targets as cost-saving device then follows the basic intuition.

#### Comparison

Let's now compare the deduced implications for the alternative cost-savings model with those of the full commitment-device model (Table 11 displays some differences). For all model versions and cases, higher social costs of carbon imply more ambitious targets (I was not able to find model assumptions with a qualitatively different  $dt^*/d\delta$ ). Yet, other implications admit to discriminate between the models. For higher private costs of carbon  $\delta$ ,

case	w	type	u	$\frac{d\Delta}{ds}$	$\frac{d\Delta}{d\delta}$	$\frac{d\Delta}{d\kappa}$	$\frac{dt^*}{ds}$	$\frac{dt^*}{d\kappa}$
(CST.1)	(+)		(-)	(+)	(+)	(-)	(+)	(-)
(CST.2)	(+)		(+)	(+)	(+)	(+)	(+)	(+)
(COM.1)	(+)	(ctr)		(+)	(+)	(-)	(+)	(-)
(COM.2)	(+)	(ust)		(-)	(-)	(+)	(+)	(-)
(CST.3)	(-)		(-)	(?)	(+)	(-)	(?)	(-)
(CST.4)	(-)		(+)	(?)	(+)	(+)	(?)	(+)
(COM.3)	(-)	(ctr)		(-)	(+)	(-)	(-)	(-)
(COM.4)	(-)	(ust)		(+)	(-)	(+)	(-)	(-)

**Table 11** Comparing models and cases (shaded rows consistent with  $\eta < 2$ )

there are some cases where the presence of targets becomes less likely (COM.2, COM.3), but this is not possible if targets are a cost-saving device.

The commitment-device model leads to the prediction that the conventional finding that larger cities are more likely to have climate targets implies: If we would also observe that more vulnerable cities less likely have climate targets, this is only consistent with  $\eta > 2$  (COM.4). The cost-savings model, however, would never be consistent with this observation. Even with also considering that targets reduce costs, the only explanation for higher- $\delta$  cities having no target remains COM.2 (and COM.4 if we admit  $\eta > 2$ ).

With respect to higher abatement costs  $\kappa$ , in the commitment-device model cities always set less ambitious targets. Now, when targets are cost-reducing, abatement costs  $\kappa$  can also be supportive for higher targets (CST.2, CST.4). If a set of cities is identified were higher mitigation costs are associated with more ambitious targets, the model with targets as commitment device is ruled out as an explanation for them. Targets as cost-saving device would yet be consistent, if *u* can be estimated to be positive. For most models/cases (except for COM.2 and  $\eta > 2$ ), mitigation costs shift both the likelihood and the target ambition in the same direction.

Finally, compare the effect of size *s*. The effect on the level or targets does not differ among the w > 0 cases, but might differ otherwise depending on how the further ambiguities are resolved (CST.3, CST.4). Among the  $\eta < 2$  cases, the commitment-device model can only explain that larger cities more likely set targets for contributor cities with if w > 0 (COM.1). Yet, two cases of the cost-savings model are also consistent (CST.1, CST.2). Interestingly, these cases also require w > 0.

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# Declarations

**Conflict of interest** I hereby declare that I have no relevant or material financial interests that relate to the research described in this paper.

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