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WP-AD 2017-03

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Versión: abril 2017 / Version: April 2017

Edita / Published by:
Instituto Valenciano de Investigaciones Económicas, S.A.
C/ Guardia Civil, 22 esc. 2 1º - 46020 Valencia (Spain)

DOI: http://dx.medra.org/10.12842/WPAD-2017-03

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Public good provision and social loss under polarization*

Ramón J. Torregrosa-Montaner**

Abstract

This paper considers a population divided into two significantly-sized groups regarding the preferences its members have about a single public good. The public good equilibrium amount is that of the majority group in such a way that it is far from the Pareto-efficient one. This allows us to characterize a social function, which depends on the inter-group heterogeneity and the relative size of each group, parameters which also compound the degree of polarization. Our main conclusion is that, in general, higher levels of polarization do not imply higher social losses. This happens whenever the higher polarization is associated with higher inter-group heterogeneity, and the change in the amount of the public good in equilibrium implied is low enough.

Keywords: Public good, majority voting equilibrium, polarization.

JEL classification numbers: D79, H41.

* I thank Agustin Casas, Luis C. Corchon, Marco Serena, Sonal Yadav and an anonymous referee for helpful comments and suggestions. This work was supported by Ministry of Economics and Competitiveness of Spain's project ECO2012-38860-C02-01. The usual caveat applies.

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1 Introduction

As is well known, non-rivalry and high-cost exclusion rule out the working of the price mechanism for the case of public good allocation. This is why political processes may arise as natural mechanisms for solving this heterogeneous-preferences aggregation problem. The simplest of these mechanisms, equivalent to markets for the case of private goods (Holcombe, 1989), is the median voter model posed by Bowen (1943), Downs (1957) and Black (1958). This model considers a continuum of individuals whose heterogeneity is characterized by a unimodal distribution of their preferences for a public good. This approach implicity assumes a moderate or middle ground point of view in public opinion, neglecting the case where such preferences are split or polarized into two extremes. Nevertheless, there is a broad set of public choice problems in which the allocation of some type of public good is involved under polarized preferences. For instance, DiMaggio, Evans and Bryson (1996) and Evans (2003) study American's polarized attitudes on political and moral issues as gender, crime and justice, abortion and sexuality; Sustein (2002) shows evidence where polarized groups decide in some institutions that allocate public-like goods, such as courts, juries, political parties, ethnic and religious groups, workplaces, and families. Moreover, in some of these cases the polarization not only implies the existence of confronted opinions but also some sort of asymmetry in favour of a dominant-majority group. For instance, Evans and Need (2002) tackle polarization as a source of majority group prejudice and negative attitudes towards minority rights in Eastern European countries. From an economic point of view, such type of polarization involves a given quantity of public-like resource (laws, rights or customs, for example) which is ruled by a majority, giving rise to a second-best allocation.

From here on, this paper proposes to study the case of a bimodal distribution of preferences using the standard model of simple-majority public good allocation. Hence, our population is gathered into two significantly-sized clusters or groups, regarding their quasi-linear preferences about a single public good, with significant intra-group homogeneity and inter-group heterogeneity. Across the model, we assume majority voting, as the rule aggregating preferences, while the public good is financed by uniform taxes. As a consequence, since one of the groups holds the majority, it rules the amount of public good. Of course, this allocation is far from the Pareto-efficient one, which also considers the preferences of the minority, such that the political equilibrium yields to a social deadweight loss. Moreover, this loss depends parametrically on the inter-group heterogeneity and the relative size of each group, which are also the parameters of Esteban and Ray's (1994) polarization measure. Our main conclusions are, on the one hand, that when higher polarization is due to a higher relative weight of the minority, social losses increase. However, when higher polarization is due to higher inter-group heterogeneity, social losses may increase or decrease, depending on the magnitude of the change in the amount of public good in equilibrium.

The structure of the paper is the usual one: a second section which describes the model, the Pareto-efficient allocation and the equilibrium, a third section which studies the effects on welfare and a fourth section with final remarks.

2 The model

There are two groups of individuals m and n belonging to a normalized population sized 1, where π is the measure of group n and $1-\pi$ is that of group m. Within each group, each individual is endowed with the same quantity w_i of numerarie and shows identical quasi-linear preferences on the quantity x_i of private good X and the quantity y of public good Y, so that

$$u_i(x_i, y) = x_i + v(\theta_i, y); \quad i = m, n.$$

For the sake of simplicity we assume that the surplus function v is equal for each group and what differs between them is only the parameter θ_i, which shows the preference of each group for the public good. We also assume that $\theta_m > \theta_n$. First, second and cross partial derivatives of v are denoted by subindexes and throughout the paper we assume that $v_y > 0, v_{yy} < 0, v_{\theta_i} > 0$ and $v_{y\theta_i} > 0$.[1] The first and second conditions are the usual ones which guarantee the existence and uniqueness of the equilibrium, and the third and four conditions say that, given a quantity of public good, an increase in its parameter of preference increases both the consumer surplus and the marginal willingness to pay for it. In other words, since $\theta_m > \theta_n,\ v(\theta_m, y) > v(\theta_n, y)$ and $v_y(\theta_m, y) > v_y(\theta_n, y)\ \forall y$. In addition, given the symmetry in the second cross derivative, $v_{y\theta_i} = v_{\theta_i y}$, the assumption of the positiveness of this second cross derivative entails that $v_{\theta_i}(\theta_i, y_1) > v_{\theta_i}(\theta_i, y_0)\ \forall y_1 > y_0$. In other words, the higher the amount of public good the higher the surplus sensibility to the parameter of preference. Finally, it is assumed that the public good absorbs $C(y) = y$ units of numerarie for its production, and $0 < \pi < \frac{1}{2}$. That is, more than half of the population has θ_m as parameter of preference for the public good. Hence, the group m is the majority and the n one is the minority.[2]

2.1 Pareto-efficient allocation

Since the preferences of consumers are quasilinear let us consider a Benthamite social welfare function such that the Pareto-efficient allocation of public good is given by the solution of

$$\max_y\ W - y + \pi v(\theta_n, y) + (1-\pi) v(\theta_m, y),$$

[1] Some examples of surplus functions v that fulfil these conditions are: the logarithmic case, $v(\theta_i, y) = \theta_i Log(y), y > 0$; the isoelastic case, $v(\theta_i, y) = \frac{\theta_i}{1-\beta} y^{1-\beta},\ \beta > 0, y > 0$; the cases, $v(\theta_i, y) = Ay - \frac{1}{\theta_i(\alpha+1)} y^{\alpha+1},\ A > 0, \alpha > 0, 0 \leq y < (\theta A)^{\frac{1}{\alpha}}$; and $v(\theta_i, y) = \theta_i y - \frac{1}{(\alpha+1)} y^{\alpha+1}$, $\alpha > 0, 0 \leq y < \theta^{\frac{1}{\alpha}}$, which generates a linear demand function when $\alpha = 1$; and the case $v(\theta_i, y) = \theta_i(1 - \frac{1}{2}y)y, 0 \leq y < 1$, which also generates a linear demand function, and will be used as example in the Section 3.

[2] If we would assume the opposite, the results across the paper would be symmetrical but the conclusions would be the same.

where $W = \pi w_n + (1-\pi)w_m$. Let $y(\pi, \theta)$ be the per-capita efficient allocation of public good which fulfils the Pareto-efficient condition:

$$\pi v_y(\theta_n, y(\pi, \theta)) + (1-\pi) v_y(\theta_m, y(\pi, \theta)) = 1. \tag{1}$$

This characterization of the per-capita efficient allocation of public good allows us to study its properties with respect to the parameters π and $\theta = (\theta_n, \theta_m)$.

Proposition 1 $\frac{\partial y(\pi,\theta)}{\partial \pi} < 0; \quad \frac{\partial y(\pi,\theta)}{\partial \theta_i} > 0, \quad i = l, h.$

Proof: Deriving the first order condition (1) with respect to π we have

$$v_y(\theta_n, y(\pi, \theta)) + \pi v_{yy}(\theta_n, y(\pi, \theta)) \frac{\partial y(\pi, \theta)}{\partial \pi} + ...$$
$$-v_y(\theta_m, y(\pi, \theta)) + (1-\pi) v_{yy}(\theta_m, y(\pi, \theta)) \frac{\partial y(\pi, \theta)}{\partial \pi} = 0,$$

and exploiting we have

$$\frac{\partial y(\pi, \theta)}{\partial \pi} = \frac{v_y(\theta_m, y(\pi, \theta)) - v_y(\theta_n, y(\pi, \theta))}{\pi v_{yy}(\theta_n, y(\pi, \theta)) + (1-\pi) v_{yy}(\theta_m, y(\pi, \theta))} < 0.$$

For the other partial derivative we derive the first order condition (1) with respect to θ_m

$$\pi v_{yy}(\theta_n, y(\pi, \theta)) \frac{\partial y(\pi, \theta)}{\partial \theta_m} + (1-\pi) \left[v_{yy}(\theta_m, y(\pi, \theta)) \frac{\partial y(\pi, \theta)}{\partial \theta_m} + v_{y\theta_m}(\theta_m, y(\pi, \theta)) \right] = 0,$$

and exploiting we have

$$\frac{\partial y(\pi, \theta)}{\partial \theta_m} = \frac{-(1-\pi) v_{y\theta_m}(\theta_m, y(\pi, \theta))}{\pi v_{yy}(\theta_n, y(\pi, \theta)) + (1-\pi) v_{yy}(\theta_m, y(\pi, \theta))} > 0.$$

For the partial derivative with respect θ_n is analogous to the former, obtaining

$$\frac{\partial y(\pi, \theta)}{\partial \theta_n} = \frac{-\pi v_{y\theta_n}(\theta_n, y(\pi, \theta))}{\pi v_{yy}(\theta_n, y(\pi, \theta)) + (1-\pi) v_{yy}(\theta_m, y(\pi, \theta))} > 0. \quad \blacksquare$$

Therefore, the higher the relative size of the minority the lower the per-capita efficient allocation of public good. This is because, a higher relative weight of this group implies lower distance between the average marginal willingness to pay for the public good and the marginal willingness to pay of the minority. On the other hand, given π, the higher the parameter of preference for the public good of any group, the higher the average willingness to pay for it, and the higher the per-capita efficient allocation of public good. In this case, the reasons are similar to the former: a higher parameter of preference for the public good implies a higher willingness to pay for it, whatever the group, with the consequence of a higher average willingness to pay for the public good.

2.2 Political equilibrium

We consider the simple majority mechanism where the public good is financed by a uniform tax T on each individual. Hence, since $0 < \pi < \frac{1}{2}$, the equilibrium allocation of public good will be that of the majority m, that is

$$\max_{x_m, y} \; x_m + v(\theta_m, y) \text{ s. t. } w_m = x_m + T,$$

where $\pi T + (1 - \pi)T = y$ or $T = y$, thus the above problem becomes

$$\max_{y} \; w_m - y + v(\theta_m, y).$$

Let $y(\theta_m)$ be the solution of this problem which fulfils its first order condition

$$v_y(\theta_m, y(\theta_m)) = 1. \tag{2}$$

Since $\theta_n < \theta_m$, it is fairly easy to see, equalling first order conditions (1) and (2), taking into account the assumptions made about the surplus function, and rearranging terms, that $y(\theta_m) > y(\pi, \theta)$ and that $\lim_{\pi \to 0} y(\pi, \theta) = y(\theta_m)$. On the other hand, we see, unlike with the per-capita efficient allocation of public good, that the per-capita allocation of public good under the political equilibrium only depends on the parameter of preference of the majority group, allowing us to state the following Proposition:

Proposition 2 $\frac{dy(\theta_m)}{d\theta_m} > 0$.

Proof: Deriving the first order condition (2) with respect to θ_h we have

$$v_{y\theta_m}(\theta_m, y(\theta_m)) + v_{yy}(\theta_m, y(\theta_m)) \frac{\partial y(\theta_m)}{\partial \theta_m} = 0,$$

and exploiting we have

$$\frac{\partial y(\theta_m)}{\partial \theta_m} = -\frac{v_{y\theta_m}(\theta_m, y(\theta_m))}{v_{yy}(\theta_m, y(\theta_m))} > 0. \quad \blacksquare$$

That is, the higher the parameter of preference for the public good of the majority the higher the per-capita allocation of public good in equilibrium.

3 Polarization and social deadweight loss

This section is concerned with the relationship between the degree of polarization and the amount of social deadweight loss. Let us begin with Esteban and Ray's (1994) polarization measure which, applied to our two-point distribution case, can be written as:

$$P(\pi, \theta) = \Gamma(\pi)\delta(\theta),$$

where $\Gamma(\pi) := \pi^{1+\alpha}(1-\pi) + (1-\pi)^{1+\alpha}\pi, \quad 0 < \alpha < 1.6$, is the identification function, and $\delta(\theta) := \theta_m - \theta_n$ is the alienation function. $\Gamma(\pi)$ is increasing in $0 < \pi < \frac{1}{2}$, reaching its maximum when $\pi \to 1/2$, which means that the more significant the proportion of individuals in the minority group the higher the degree of polarization. On the other hand, a higher difference $\theta_m - \theta_n$, implies higher heterogeneity, or alienation, across groups and, thus, higher polarization. Therefore, given a vector of parameters of preference for the public good $\theta = (\theta_l, \theta_h)$, an increase in the alienation function implies an enhancement of the interval $\delta(\theta)$. For the sake of convenience, let $d\theta_m > 0$ be the marginal increase in the majority's alienation, and let $d\theta_l = -\gamma d\theta_h < 0$ be the marginal increase in the minority's alienation, where γ is its relative marginal increase. Then the marginal increase in the inter-group heterogeneity can be written as:

$$d\delta = (1+\gamma)d\theta_h > 0, \tag{3}$$

On the other hand, the social deadweight loss function also depends on the parameters (π, θ) so that,

$$L(\pi, \theta) = V(\pi, \theta) - V(\pi, \theta_m),$$

where

$$V(\pi, \theta) = W - y(\pi, \theta) + \pi v(\theta_n, y(\pi, \theta)) + (1-\pi)v(\theta_m, y(\pi, \theta)),$$

is the total surplus evaluated in the Pareto-efficient allocation and

$$V(\pi, \theta_m) = W - y(\theta_m) + \pi v(\theta_n, y(\theta_m)) + (1-\pi)v(\theta_m, y(\theta_m)),$$

is the total surplus evaluated in the political equilibrium. Thus,

$$\begin{aligned} L(\pi, \theta) \quad = \quad & y(\theta_m) - y(\pi, \theta) + \pi \left[v(\theta_n, y(\pi, \theta)) - v(\theta_n, y(\theta_m))\right] + ... \\ & +(1-\pi)\left[v(\theta_m, y(\pi, \theta)) - v(\theta_m, y(\theta_m))\right], \end{aligned} \tag{4}$$

is the social deadweight loss generated in political equilibrium. The following Propositions map $L(\pi, \theta)$ with respect the relative size of the minority, π, and the inter-group heterogeneity, δ.

Proposition 3 $\frac{\partial L(\pi,\theta)}{\partial \pi} > 0$.

Proof: Deriving (4) with respect to π,

$$\begin{aligned}\frac{\partial L(\pi,\theta)}{\partial \pi} &= -\frac{\partial y(\pi,\theta)}{\partial \pi} + v(\theta_l, y(\pi,\theta)) - v(\theta_l, y(\theta_h)) + \pi v_y(\theta_l, y(\pi,\theta))\frac{\partial y(\pi,\theta)}{\partial \pi} + ... \\ & - [v(\theta_h, y(\pi,\theta)) - v(\theta_h, y(\theta_h))] + (1-\pi)v_y(\theta_h, y(\pi,\theta))\frac{\partial y(\pi,\theta)}{\partial \pi}.\end{aligned}$$

Taking into account the Pareto-efficient condition (1),

$$\frac{\partial L(\pi,\theta)}{\partial \pi} = v(\theta_l, y(\pi,\theta)) - v(\theta_l, y(\theta_h)) - [v(\theta_h, y(\pi,\theta)) - v(\theta_h, y(\theta_h))],$$

or

$$\frac{\partial L(\pi,\theta)}{\partial \pi} = \int_{y(\pi,\theta)}^{y(\theta_h)} [v_y(\theta_h, y) - v_y(\theta_l, y)]\, dy > 0. \blacksquare$$

That is, the higher the relative weight of the minority group the higher the social deadweight loss. This result is consequence of Proposition 1, where the higher the relative size of the minority group the lower the per-capita efficient allocation of public good, and the fact that the political equilibrium public good allocation does not change with changes in π. Hence, the deadweight loss generated by a higher π is equivalent to the difference between the variation in consumer surplus of the majority minus that of the minority, when the amount of public good changes from the efficient one to that of political equilibrium.

Proposition 4 $\frac{dL(\pi,\theta)}{d\delta} \gtrless 0$ *whenever* $\frac{\partial y(\theta_m)}{\partial \theta_m} \gtrless \frac{\int_{y(\pi,\theta)}^{y(\theta_m)}[(1-\pi)v_{y\theta_m}(\theta_m,y) - \gamma\pi v_{y\theta_n}(\theta_n,y)]dy}{\pi[1-v_y(\theta_n, y(\theta_m))]}$.

Proof: Total differential of total surplus, taking into account $d\theta_n = -\gamma d\theta_m$, and $d\theta_m > 0$, can be written as:

$$\frac{dL(\pi,\theta)}{d\theta_m} = \frac{\partial L(\pi,\theta)}{\partial \theta_m} - \gamma\frac{\partial L(\pi,\theta)}{\partial \theta_n},$$

where, taking into account Equation (3)

$$\frac{dL(\pi,\theta)}{d\delta} = \frac{1}{1+\gamma}\left[\frac{\partial L(\pi,\theta)}{\partial \theta_m} - \gamma\frac{\partial L(\pi,\theta)}{\partial \theta_m}\right]. \tag{5}$$

To assess the sign of Equation (5) let us gauge partial derivatives of Equation (4) with respect to θ_l and θ_h,

$$\begin{aligned}\frac{\partial L(\pi,\theta)}{\partial \theta_n} = -\frac{\partial y(\pi,\theta)}{\partial \theta_n} + \pi\Big[v_y(\theta_n, y(\pi,\theta))\frac{\partial y(\pi,\theta)}{\partial \theta_n} + ... \\ + v_{\theta_n}(\theta_n, y(\pi,\theta)) - v_{\theta_n}(\theta_n, y(\theta_h))\Big] + (1-\pi)v_y(\theta_m, y(\pi,\theta))\frac{\partial y(\pi,\theta)}{\partial \theta_n},\end{aligned}$$

$$\frac{\partial L(\pi,\theta)}{\partial \theta_m} = \frac{\partial y(\theta_m)}{\partial \theta_m} - \frac{\partial y(\pi,\theta)}{\partial \theta_m} + \pi \left[v_y(\theta_n, y(\pi,\theta)) \frac{\partial y(\pi,\theta)}{\partial \theta_m} - v_y(\theta_n, y(\theta_m)) \frac{\partial y(\theta_m)}{\partial \theta_m} \right] + ...$$
$$+(1-\pi) \left[v_y(\theta_m, y(\pi,\theta)) \frac{\partial y(\pi,\theta)}{\partial \theta_m} - v_y(\theta_m, y(\theta_m)) \frac{\partial y(\theta_m)}{\partial \theta_m} + v_{\theta_m}(\theta_m, y(\pi,\theta)) - v_{\theta_m}(\theta_m, y(\theta_m)) \right].$$

Taking into account Equations (1) and (2), and simplifying

$$\frac{\partial L(\pi,\theta)}{\partial \theta_n} = -\pi \int_{y(\pi,\theta)}^{y(\theta_m)} v_{y\theta_n}(\theta_n, y) dy < 0, \quad (6)$$

$$\frac{\partial L(\pi,\theta)}{\partial \theta_m} = \pi \left[1 - v_y(\theta_n, y(\theta_m))\right] \frac{\partial y(\theta_m)}{\partial \theta_m} - (1-\pi) \int_{y(\pi,\theta)}^{y(\theta_m)} v_{y\theta_m}(\theta_m, y) dy. \quad (7)$$

Substituting (7) and (6) in (5) the statement holds. ■

Proposition 4 states that the shape of the social deadweight loss function with respect the intergroup heterogeneity, depends monotonically on the parameters of the model in such a way that, in general, a higher degree of alienation or inter-group heterogeneity does not imply higher social deadweight loss. To proof this statement, the marginal enhancement of the inter-group heterogeneity is split into two parts. On the one hand, the marginal increase in the minority's alienation, described by Equation (6), shows that the lower the parameter of preference for the public good of the minority, the higher the social deadweight loss. According to Proposition 1, this partial effect is due to the fact that a lower value of this parameter implies a lower amount of per-capita efficient allocation of public good. On the other hand, the marginal increase in the majority's alienation, described by Equation (7), shows that the higher the parameter of preference for the public good of the majority, the higher both the per-capita efficient allocation of public good (Proposition 1) and the per-capita political equilibrium amount of public good (Proposition 2). The first effect makes the minority group worse off: a higher amount of public good in equilibrium implies a fall in this group's willingness to pay, and the social deadweight loss arises as the difference between its valuation and the marginal cost times the change in the amount of public good in equilibrium. The second effect shows how the higher the preference for the public good of the majority increases both its own and the average willingness to pay for it, with the result of a fall in the social deadweight loss. In the end, the sign of the change upon the social deadweight loss of the marginal enhancement of heterogeneity due to an increase in θ_m, depends on how the amount of public good in equilibrium changes with respect to a sized-weighted ratio which measures the increase in the majority surplus sensibility to its parameter of preference, over the difference between the public good marginal cost and the minority's willingness to pay for it. In turn, with regard to the total effect, that is, when inter-group heterogeneity is enhanced by its two extremes, the explanation is similar to that of the marginal increase in the majority's alienation but, owing the fact that a lower minority's parameter of preference shifts inward the average willingness to pay curve, drawing in the per-capita efficient allocation of public good, the increase in the per-capita political equilibrium amount of public good induced by such a enhancement is now constricted by the parameter γ. In particular, the condition $\gamma \leq \frac{(1-\pi)v_{y\theta_m}(\theta_m,y)}{\pi v_{y\theta_n}(\theta_n,y)}$ has to be held to make the right-hand side of the statement of Proposition 4 positive. The following example shows conditions for which social deadweight loss decreases as a consequence of an increase in inter-group heterogeneity, according to Proposition 4, for a fairly common surplus function case.

Example:

For the case $v(\theta_i, y) = \theta_i(1 - \frac{1}{2}y)y$, $i = m, n$; $\theta_n = 1 < \theta_m$, there exists $\theta_m^* > 1$ so that,$\forall\theta_m \geqslant \theta_m^*$, $\frac{dL(\pi,\theta)}{d\delta} < 0$ according to Proposition 4. This threshold determines the least heterogeneity across groups, $\delta^* = \theta_m^* - 1$, for which the statement of Proposition 4 occurs. In the Appendix it is shown that $\gamma < 1/3$ is a sufficient condition for this result, $\forall\pi \in \left(0, \frac{1}{2}\right)$. The Table below illustrates the relationship among the values of the least heterogeneity across groups, δ^*, and both the relative weight the minority, π, and the relative marginal increase in the minority group's alienation, γ. As seen, both a lower π and γ, allow a lower heterogeneity across groups for which social losses decrease according to Proposition 4.

δ^*	$\gamma = 0.3$	$\gamma = 0.2$	$\gamma = 0.1$	$\gamma = 0.0$
$\pi = 0.4$	15.4	6.1	3.6	2.4
$\pi = 0.3$	10.8	5.3	3.3	2.3
$\pi = 0.2$	8.6	4.7	3.1	2.2
$\pi = 0.1$	7.3	4.3	2.9	2.1

4 Final remarks

This paper studies a simple public good majority-voting allocation model, where the parameter of preference for the public good of a population of quasilinear-preference individuals, is distribute in a bimodal way. This feature splits individuals into two groups. One of the groups is the majority, such that it rules the equilibrium amount of public good. This equilibrium generates a social deadweight loss since it is far from the efficient allocation. In this standard framework, we find that the claim which relates a higher degree of polarization to a higher level of social deadweight loss, is not true in general. This could happen whenever the higher polarization comes from a higher degree of alienation or heterogeneity across groups. In this case both the efficient and the majority voting equilibrium are affected, in such a way that the surplus of both the minority group and majority one changes. The higher the heterogeneity the better off the majority group, since it rules the amount of public good in equilibrium, but the worse off the minority. The final effect on social deadweight loss depends on the balance between these two changes regarding the change in the amount of public good in equilibrium. A further extension of this model may be that which considers a multinomial distribution of the parameter of preference for the public good, a case in which political equilibrium would be ruled by coalitions of those groups that are closely related, and the casuistic of polarization would be enriched.

Appendix:

For the case $v(\theta_i, y) = \theta_i(1 - \frac{1}{2}y)y$, $i = m, n$; $\theta_n = 1 < \theta_m$, the condition $\frac{dL(\pi,\theta)}{d\delta} \leq 0$ of Proposition 4 can be written as $g_1(\pi, \theta_m) \leq g_2(\pi, \theta_m, \gamma)$ where,

$$g_1(\pi, \theta_m) = 2\pi(1 - 1/\theta_m),$$
$$g_2(\pi, \theta_m, \gamma) = (1 - (1 + \gamma)\pi)\left[\frac{\theta_m^2}{(\pi + (1 - \pi)\theta_m)^2} - 1\right].$$

It is fairly easy to see that both $g_1(\pi, \theta_m)$ and $g_2(\pi, \theta_m, \gamma)$ are increasing and concave with respect to $\theta_m > 1$; $\lim_{\theta_m \to 1} g_1(\pi, \theta_m) = \lim_{\theta_m \to 1} g_2(\pi, \theta_m, \gamma) = 0$; and $\lim_{\theta_m \to \infty} g_1(\pi, \theta_m) = 2\pi$, $\lim_{\theta_m \to \infty} g_2(\pi, \theta_m, \gamma) = (1 - (1 + \gamma)\pi)\pi(2 - \pi)(1-\pi)^{-2}$. Thus, there exists $\theta_m^* > 1$ so that,$\forall \theta_m \geqslant \theta_m^* \quad g_1(\pi, \theta_m) \leq g_2(\pi, \theta_m, \gamma)$, whenever $2\pi \leq (1 - (1 + \gamma)\pi)\pi(2 - \pi)(1 - \pi)^{-2}$. Solving the inequation yields the condition $\pi \leq \frac{1-2\gamma}{1-\gamma}$, which holds $\forall \pi \in \left(0, \frac{1}{2}\right)$ whenever $\gamma < 1/3$.

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