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Public debt stabilization: Redistributive delays versus preemptive anticipations

Paulo Júlio

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Paulo Júlio

Gabinete de Estratégia e Estudos, Portuguese Ministry of Economy and Employment
Email: paulo.julio@gee.min-economia.pt

JEL Classification: D72, E60

Keywords: Stabilization delays, Economic adjustments, Economic reforms, Majority voting

* The opinions expressed in this article represent the view of the author and do not necessarily correspond to those of the Ministry of Economy and Employment.

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Public debt stabilization: Redistributive delays versus preemptive anticipations*

Paulo Júlio[†]

November 18, 2011

Abstract

This article illustrates and formalizes the conditions under which majority voting can lead to either delays or anticipations in public debt stabilizations. Under the assumptions of proportional taxation and universal public expenditures, we present an intertemporal version of the “Meltzer–Richard” result, which captures the difficulty of controlling increases in public expenditures. In the benchmark model delays are endogenous and have redistributive effects, but when a relatively rich minority makes the decisions, we may observe anticipation in public debt stabilization. *JEL Classification:* D72, E60

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[†]*Gabinete de Estratégia e Estudos*, Portuguese Ministry of Economy and Employment. E-mail: paulo.julio@gee.min-economia.pt

1 Introduction

Over the past century, various populist policies were adopted in several countries in Latin America. Examples include Argentina (1946–49), Chile (1971–73), Brasil (1985–88) and Peru (1985–88). Behind these policies lies a common factor—high income inequality—which lead left and right wing governments to rapidly increase the size of government, financing public expenditures through public debt in order to attain various distributional goals. The final result was high inflation and a balance of payment crisis. On the opposite direction, some historical episodes suggest that the lack of a legislature is associated with low public good provision. Some examples can be found in Argentina, during the military rule (1976–83), when the access to safe water declined sharply, and in Nigeria, where the number of children in school and the number of younger than 1 immunized against diphtheria, pertussis, and tetanus decreased significantly between 1982–85 (Lake and Baum, 2001).

At least since Alesina and Drazen (1991) published their findings, there has been a rich discussion in the literature on the causes of delayed economic adjustments.¹ In their influential article, “Why are Stabilizations Delayed?”, these authors justify delayed stabilizations over the level of debt through a “war of attrition” game between different socioeconomic groups. The initial situation imposes different utility losses (from distortionary taxation) across groups. The true cost is known only to each group, while the other group knows only the distribution function of the cost. Economic reforms, including those necessary to eliminate budget deficits, inflict costs that are unevenly distributed across society, with the first group to concede having to face the highest share of the burden. Delays are just the result of each group trying to wait as long as possible, hoping that the other group concedes first and agrees to carry the highest share of the cost of adjustment. Drazen and Grilli (1993) extended this idea by analyzing how a “war of attrition” can be waged in a society that finances budget deficits by issuing money.

More recently, Spolaore (2004) examined how different political settings result in delays or anticipations for three types of government systems: cabinet systems, consensus systems, and checks-and-balances systems. The majority rule, which is perhaps the most popularized decision rule in political economy, dating back to Romer (1975), Roberts (1977), and Meltzer and Richard (1981), oddly seems to have been systematically left out of this field. In this paper we seek to correct this fault, by establishing the majority rule as the decision rule to analyze the timing of fiscal stabilizations. We do this by associating delays in economic adjustments with an increasing pattern of government expenditures over time, and examining when and how the median voter would react to this process. Our paper also formalizes delays and anticipations, but using information on how fundamentals such as income distribution interact with the fiscal system.

¹See also Drazen and Grilli (1993), Casella and Eichengreen (1996), Velasco (1998), Martinelli and Escorza (2007) and Myatt (2005).

Under the traditional assumptions of proportional taxation and universal expenditures, we capture not only the patterns for delaying economic adjustments, but also the upward trend in expenditures and the difficulty in cutting them after each increase, the so called “ratchet effect.” Our result is driven by the redistributive aspirations of the median voter, who delays stabilizations to transfer resources from the wealthiest individuals to the poorest—a situation we term “redistributive delays.”

Under the more general assumption that public expenditures provide uneven benefits across citizens, as in the case of targeted expenditures, the median voter may find himself in a position of being expropriated by the political system—a situation in which he prefers to undertake a “preemptive anticipation.” Stabilizing is the means the median voter uses to avoid more excessive redistribution. A similar outcome holds when the preferences of richer citizens have a greater weight in decision-making, even without targeting.²

This article is organized as follows. Section 2 sets up the model and describes its particular features. Section 3 discusses delays and anticipations. Section 4 concludes.

2 The model

We consider an economy where government uses its income to provide a public-financed good to all agents in the economy,³ with a direct impact on utility. The model is set in continuous time. We assume no economic growth, so that income is constant through time.

2.1 Budgetary framework

Consider a small open economy which issues external debt to cover deficits not covered by revenues, and let r denote the constant world interest rate. Initially this economy has no budget deficit. If we let $g(t)$ denote primary public spending,⁴ $\tau(t)$ the level of taxes and $b(t)$ the level of debt, at time t , the budget constraint up to and including moment $t = 0$ is given by

$$g(t) + rb(t) = \tau(t), \quad t \leq 0 \tag{1}$$

Let us assume that, at $t = 0$, an exogenous shock falls over the rate of growth of public expenditures. More specifically, consider that, from $t = 0$ until a policy change, primary public expenditures grow at an exogenous rate $\gamma > 0$. This setup translates government spending into a temporal framework in a simple way, shifting the discussion from the size of government to the date of stabilization. Besides, it connects growth in public spending to public debt, a relationship that a static model cannot incorporate. One can consider

²A related result, although in a different context, can be found in Rodríguez (2004).

³For the sake of the discussion, we use public expenditure and public-financed good interchangeably.

⁴To ease the exposition, we refer to primary public expenditures as public expenditures. Whenever we wish to refer to total public expenditures (including interest payments), we emphasize it explicitly.

that selecting the size of government every period is too costly, as it requires immediate stabilizations which are hard to implement. Hence

$$g(t) = g(0)e^{\gamma t}, \quad t \in [0, T)$$

where T is the date of the policy change. Assume also that this increase in public spending is only partially reflected in taxes

$$\tau(t) = \tau(0) + \alpha [g(t) + rb(t) - \tau(0)], \quad t \in [0, T]; \quad \text{with } \alpha \in [0, 1) \quad (2)$$

where $1 - \alpha$ is the fraction of the increase in total expenditures financed by issuing debt (deficit bias). Hence, between $t = 0$ until an economic adjustment, the level of debt evolves according to

$$\dot{b}(t) = g(t) + rb(t) - \tau(t) = (1 - \alpha) [g(t) + rb(t) - \tau(0)], \quad t \in [0, T) \quad (3)$$

Let us assume that $\gamma \neq r(1 - \alpha)$. Then, equation (3) may be solved to yield⁵

$$b(t) = b(0)e^{r(1-\alpha)t} + (1 - \alpha) [g(0)\zeta(t; \gamma, r, \alpha) - \tau(0)\zeta(t; 0, r, \alpha)], \quad t \in [0, T) \quad (4)$$

where

$$\zeta(t; \gamma, r, \alpha) = \frac{e^{\gamma t} - e^{r(1-\alpha)t}}{[\gamma - r(1 - \alpha)]}$$

Equation (4) states that the level of debt at moment t is the sum of the debt at moment 0 with the overall impact of the accumulated deficits between moment 0 and t , including interest payments. The term $\zeta(t; \gamma, r, \alpha)$ measures the present value factor of the impact of a variable growing at rate γ , given a discount rate r and a deficit bias $1 - \alpha$, in the level of debt at time t .

A stabilization in this setup consists of setting the growth rate of public spending equal to zero, plus an increase in taxes that prevents further growth in the level of debt. Therefore, taxes from the date of stabilization T onwards are

$$\tau(t) = g(T) + rb(T), \quad t \in [T, +\infty) \quad (5)$$

where $g(T) = g(0)e^{\gamma T}$, and where $b(T)$ is given by equation (4) evaluated at $t = T$, *i.e.*, the debt accumulated between 0 and T . Hence, $\dot{b}(t) = 0, \quad \forall t \geq T$.

Notice that public spending grows exponentially from $t = 0$ until a policy change, but remains constant thereafter, while taxes cover this increase only partially, but face a one-time jump at $t = T$ in order to achieve budget balance thereafter. The level of debt is increasing from time zero until the date of stabilization, but remains constant thereafter.

⁵If $\gamma = r(1 - \alpha)$, the differential equation would change, but all results presented here remain valid.

2.2 Individual decision-making

Let us now introduce heterogeneous agents and analyze the date of stabilization preferred by each individual. We consider the economy to be populated by a continuum of citizens with mass of unity. Each citizen, indexed by i , is characterized by his—exogenous, constant and strictly positive—income $y_i \in [\underline{y}, \bar{y}]$, which is drawn from a cumulative distribution $F_y(y)$, according to a density function $f_y(y)$. This p.d.f. is assumed to be single-peaked and skewed to the right, such that $y_{med} < E(y)$, where y_{med} is the median income and $E(\cdot)$ denotes the expected value operator. Also, define $\varkappa_i = y_i/E(y)$ as the relative income of citizen i , and interpret $\varkappa_{med} = y_{med}/E(y)$ as a measure of inequality in income distribution in the society: the higher is \varkappa_{med} , the more equally is income distributed.

Letting θ denote the public good preference parameter, and defining $c_i(t)$ as the consumption at moment t , the flow utility of agent i at time t , denoted by $u_i(t)$, is

$$u_i(t) = c_i(t) - y_i + \theta \cdot v(g(t)), \quad \theta > 0$$

with $v'(g(t)) > 0$ and $v''(g(t)) < 0$.⁶ Let $U_i(c_i^D(t), c_i^R(t); T)$ denote the lifetime utility of agent i , where $c_i^D(t)$ is the consumption path before stabilization and $c_i^R(t)$ is the consumption after the reform package has been adopted. Assume, for simplicity, that the discount rate of an individual equals the interest rate.⁷ Then her lifetime utility, if a stabilization occurs at time T , is

$$\begin{aligned} U_i(c_i^D(t), c_i^R(t); T) &= \int_0^T [c_i^D(t) - y_i + \theta \cdot v(g(t))] e^{-rt} dt + \\ &+ \int_T^\infty [c_i^R(t) - y_i + \theta \cdot v(g(T))] e^{-rt} dt \end{aligned} \quad (6)$$

As usual in the literature, we assume that each individual faces a proportional tax rate. In particular, an individual in this economy pays taxes totaling $\delta(t) \cdot y_i$, where $\delta(t)$ is the tax rate, assumed to be equal for all citizens. One could consider distortionary taxation *à la* Barro, but our main conclusions carry through to this case.⁸ The individual budget constraint can thus be written as

$$\begin{aligned} &\int_0^T c_i^D(t) e^{-rt} dt + \int_T^\infty c_i^R(t) e^{-rt} dt = \\ &= \int_0^T [y_i(1 - \delta(t))] e^{-rt} dt + \int_T^\infty [y_i(1 - \delta(t))] e^{-rt} dt \end{aligned} \quad (7)$$

⁶We also assume that $\lim_{g(t) \rightarrow 0} v'(g(t)) = \infty$ and $\lim_{g(t) \rightarrow \infty} v'(g(t)) = 0$. Linearity in consumption is used for analytical tractability. Subtracting y_i in the utility function was first suggested in Alesina and Drazen (1991), and constitutes a simple normalization that does not affect any conclusions. Its role will become apparent in the sequel.

⁷This assumption is standard in the economics literature.

⁸Our working paper provides a more extensive discussion of this issue.

while total tax income in the economy at time t is

$$\tau(t) = \delta(t) \cdot \int y f_y(y) dy = \delta(t) \cdot E(y)$$

which implies that the tax rate at each moment in time is simply $\delta(t) = \tau(t)/E(y)$. The time path of taxes, given by equations (1), (2) and (5), allows us to re-write the tax rate as

$$\delta(t) = \begin{cases} \frac{(1-\alpha) \cdot [g(0) + rb(0)] + \alpha \cdot [g(t) + rb(t)]}{E(y)} & , t \in [0, T) \\ \frac{g(T) + rb(T)}{E(y)} & , t \geq T \end{cases} \quad (8)$$

Using (8), the individual budget constraint in (7) becomes

$$\begin{aligned} & \int_0^T c_i^D(t) e^{-rt} dt + \int_T^\infty c_i^R(t) e^{-rt} dt = \\ & = \int_0^T \left[y_i - \kappa_i \left((1-\alpha) \cdot (g(0) + rb(0)) + \alpha \cdot (g(t) + rb(t)) \right) \right] e^{-rt} dt + \\ & + \int_T^\infty \left[y_i - \kappa_i (g(T) + rb(T)) \right] e^{-rt} dt \end{aligned} \quad (9)$$

Plugging (9) into (6) we can obtain the indirect lifetime utility of agent i as a function of the stabilization date T

$$\begin{aligned} U_i(T) &= \\ &= \int_0^T \left[-\kappa_i \left((1-\alpha) (g(0) + rb(0)) + \alpha (g(t) + rb(t)) \right) + \theta \cdot v(g(t)) \right] e^{-rt} dt + \\ &+ \int_T^\infty \left[-\kappa_i (g(T) + rb(T)) + \theta \cdot v(g(T)) \right] e^{-rt} dt \end{aligned} \quad (10)$$

where we choose not to substitute $b(t)$ and $b(T)$ for their expressions, so that the equation does not become too cumbersome. Notice that subtracting y_i in the flow utility was just a simplification, which becomes advantageous here.

3 Delays or anticipations

3.1 Individual i 's desired policy

The preferred date of stabilization of an individual with income y_i is found by maximizing (10) with respect to T , subject to the condition $T \geq 0$.⁹ The result can be summarized as

⁹We assume throughout that the condition $v'^{-1}(1/\theta) > g(0)$ is satisfied. This assumption implies that any citizen with an income equal to or below per capita income ($\kappa_i \leq 1$) does not want to undertake an immediate stabilization.

follows.¹⁰

Proposition 1. *The preferred date of stabilization for citizen i is given by*

$$T_i^* = \begin{cases} \frac{1}{\gamma} \log \left(\frac{v'^{-1}(\theta^{-1} \cdot \varkappa_i)}{g(0)} \right) & , \text{ if } v'^{-1}(\theta^{-1} \cdot \varkappa_i) > g(0) \\ 0 & , \text{ otherwise} \end{cases} \quad (11)$$

For $g(0) < v'^{-1}(\theta^{-1} \cdot \varkappa_i)$, (11) may be written as

$$\frac{d}{dT} [\theta \cdot v(g(T))] \Big|_{T=T_i^*} - \varkappa_i \cdot \frac{d}{dT} [g(T)] \Big|_{T=T_i^*} = 0$$

The left-hand side is the net marginal benefit of delaying the stabilization another instant, evaluated at T_i^* , for citizen i . Hence, agent i would prefer to stabilize when the gain generated by the increase in government expenditures for him is exactly offset by the increase in taxes he faces to finance the higher level of primary government spending originated by delaying the stabilization another instant.¹¹ Notice that neither the level of debt nor the fraction of the increase in total government expenditures that is financed with deficits before the stabilization (that is $1 - \alpha$) have any impact on T_i^* . In fact, delaying the adjustment another instant implies an increase in the interest over that period, which has to be paid later on. As the benefits and costs of this process are exactly equal, they cancel each other out. Observe that while the gain from delaying stabilizations is equal for all citizens, the increase in the amount of taxes each agent faces depends on the relative income. This implies that poor agents desire to stabilize later, as they face a lower incentive to support stabilizations. Table 1 summarizes this and other effects of parameters over the preferred time for stabilization T_i^* when (11) does not yield a corner solution.

Table 1: *The effects of parameters over the preferred time for stabilization*

| Variable | Parameter | Effect | Reason |
|--------------------------------------|---------------|--------|---|
| Growth rate of public expenditures | γ | – | The desired level of expenditures is attained sooner |
| Initial value of public expenditures | $g(0)$ | – | Initially, expenditures are closer to the desired level |
| Relative income | \varkappa_i | – | Agent pays more taxes for a given stabilization date |
| Preference for public expenditures | θ | + | The weight of public expenditures in utility increases |

¹⁰ All proofs are relegated to the appendix.

¹¹ Observe that taxes at time T are given by $\tau(T) = g(T) + rb(T)$. Hence

$$\frac{d}{dT} [\tau(T)] \Big|_{T=T_i^*} = \frac{d}{dT} [g(T)] \Big|_{T=T_i^*} + r \frac{d}{dT} [b(T)] \Big|_{T=T_i^*}$$

The effect mentioned in the text concerns only the first term. Taxes will also increase to pay for the interest associated with the enlargement of the level of debt arising from this delay.

3.2 The benevolent social planner's preferred policy

We now turn to the preferred date of stabilization for a benevolent social planner. We consider a utilitarian social welfare function, a very common and standard approach in the literature to define optimal solution concepts.¹² If we assume that the social planner's objective is to maximize the expected utility of the economy, then he solves

$$\max_T \int_i U(T) f_y(y) dy, \text{ s.t. } T \geq 0$$

The result is summarized in the following proposition.

Proposition 2. *The optimal stabilization date is defined by*

$$T_{opt}^* = \frac{1}{\gamma} \log \left(\frac{v'^{-1}(\theta^{-1})}{g(0)} \right) \quad (12)$$

Moreover, $g(T_{opt}^*) = v'^{-1}(\theta^{-1})$.

In order to interpret equation (12), it is useful to re-write it as

$$\frac{d}{dT} [\theta \cdot v(g(T))] \Big|_{T=T_{opt}^*} - \frac{d}{dT} [g(T)] \Big|_{T=T_{opt}^*} = 0$$

Hence, it is optimal for the social planner to stabilize when the gain generated by the increase in government expenditures for the society from delaying the stabilization is exactly offset by the increase in taxes the society has to pay in order to finance the higher level of public expenditures if it were to delay the stabilization another instant. Notice that while the social planner considers the same gain from delays as any other citizen (since the benefit from public expenditures does not vary across citizens), he takes into account only the average cost of this process in his decision-making, and not any specific cost for any individual. Importantly, he does not necessarily consider the cost of delaying the stabilization for the median voter.

3.3 Policy-makers, delays and anticipations

3.3.1 The median policy-maker and redistributive delays

Clearly, the lower the relative income of the policy-maker, the larger the stabilization date and the more overwhelmed the government will be. In what follows, we allow this decision-maker to be selected by majority voting.

¹²Notice that the application of a utilitarian objective function is not very restrictive when used in conjunction with quasi-linear preferences, since these rule out distributional considerations (see Persson and Tabellini, 2000).

We immediately see that unidimensionality and single-peakedness of preferences is verified. Hence, a Condorcet winner always exists. Under majority voting, the timing of stabilization is then the one chosen by the median voter, the citizen with a relative income \varkappa_{med}

$$T_{med}^* = \frac{1}{\gamma} \log \left(\frac{v'^{-1}(\theta^{-1} \cdot \varkappa_{med})}{g(0)} \right)$$

which is positive. Thus, stabilizations are postponed beyond what is optimal. The delay lag can be written as

$$T_{med}^* - T_{opt}^* = \frac{1}{\gamma} \log \left(\frac{v'^{-1}(\theta^{-1} \cdot \varkappa_{med})}{v'^{-1}(\theta^{-1})} \right)$$

which is always strictly greater than zero when the decision-maker is the median voter. Recall that, as $\varkappa_{med} < 1$, the median voter is contributing less to finance public goods than the society. That is, all citizens have the same benefit from public goods, but those individuals whose income is less than or equal to the median face a lower cost of provision of these goods. Therefore, all of these citizens, who constitute a majority, vote for delaying stabilizations, thereby increasing government expenditures above the optimal level, and indirectly transferring resources from the richest individuals straight to them—A “redistributive delay.”¹³ In other words, the median voter has few resources to spend in consumption and finds in delays a way to increase his utility at the expense of the wealthiest citizens, who will bear a larger fraction of the burden later on. The richest individuals are therefore expropriated by the political system. Moreover, the lower is the median voter’s income, the lower is the cost of providing public goods according to his perspective, and so the greater the delay lag and the expropriation faced by high income classes.

Once the stabilization is achieved, public expenditures tend to remain constant, but at a higher level than what would be optimal. This result can be interpreted as an intertemporal version of the “Meltzer–Richard result” (Meltzer and Richard, 1981, 1983). It also mimics the the so-called “ratchet effect,” the upward trend in public spending and the difficulty in cutting public expenditures that characterize many countries.

3.3.2 The wealthy policy-maker and preemptive anticipations

Let us now consider the case of a policy-maker whose preferences are in accordance with the fraction M of the richest citizens, where M is small. In particular, suppose that the relevant income for this policy-maker is not the median income, but an income of

¹³Notice that here, as in Alesina and Drazen (1991), as time passes the amount of redistribution increases.

$y_R > E(y)$. Letting $\varkappa_R = y_R/E(y)$, the delay lag is¹⁴

$$T_R^* - T_{opt}^* = \frac{1}{\gamma} \log \left(\frac{v'^{-1}(\theta^{-1} \cdot \varkappa_R)}{v'^{-1}(\theta^{-1})} \right)$$

which is clearly negative. As compared to the optimal policy, this policy-maker anticipates the date of stabilization, in a clear attempt to reduce the size of government and to avoid being expropriated by the poor, who would like a larger government, since they carry a smaller fraction of the total tax burden. In other words, the wealthy policy-maker, when in power, preempts redistribution by anticipating a stabilization relative to the decision a benevolent social planner would make.

3.3.3 The median policy-maker and preemptive anticipations

A result similar to the previous one can be obtained when the decision is carried out by the median voter, but a large fraction of public expenditures is targeted to a share $X < 0.5$ of the poorest citizens. To see this, suppose that, besides providing a universal public good, $g_u(t)$, the government implements a targeted welfare program, $g_{tg}(t)$. The latter allows a higher consumption to poorest citizens. For simplicity, assume that the welfare program consists of uniform lump-sum transfers to all citizens whose income is equal to or below a given threshold level, \tilde{y} , $\tilde{y} < y_{med}$. Letting \tilde{x} denote the measure of all eligible citizens, each eligible citizen receives a lump-sum transfer of $g_{tg}^i(t) = g_{tg}(t)/\tilde{x}$. Both types of expenditures are financed by proportional taxation. Also, let $g(t) = g_u(t) + g_{tg}(t)$, $\forall t$, and assume that from $t = 0$ until a policy change, both types of expenditures grow at the same rate $\gamma > 0$, but remain constant thereafter.¹⁵ In this case, the indirect lifetime utility of agent i as a function of the stabilization date T becomes

$$U_i(T) = \int_0^T [-\varkappa_i(g(0) + rb(0)) + g_{tg}^i(t) + \theta \cdot v(g_u(t))] e^{-rt} dt + \\ + \int_T^\infty [-\varkappa_i(g(T) + rb(T)) + g_{tg}^i(T) + \theta \cdot v(g_u(T))] e^{-rt} dt$$

where $g_{tg}^i(t)$ takes the value of $g_{tg}(t)/\tilde{x}$ if $y_i < \tilde{y}$ and 0 otherwise.

Using the same steps as in the benchmark model, and noting that the median voter does not benefit from the targeted welfare program, we obtain the delay lag

$$T_{med}^* - T_{opt}^* = \frac{1}{\gamma} \log \left[\frac{v'^{-1}(\theta^{-1} \cdot \varkappa_{med}/\tilde{g}_u(0))}{v'^{-1}(\theta^{-1})} \right]$$

¹⁴We are implicitly assuming that $T_R^* = (1/\gamma) \log(v'^{-1}(\theta^{-1} \cdot \varkappa_R)) \geq 0$, otherwise, the delay lag would be $-T_{opt}^*$. The analysis, however, remains unchanged under this alternative scenario.

¹⁵We recognize that a more general model should consider the choice between universal and targeted expenditures as endogenous, but for our purpose it is enough to introduce concerns over social inequality through exogenous targeted expenditures.

where $\tilde{g}_u(0) = g_u(0)/g(0)$. In this case, T_{opt}^* does not depend on the level of targeted expenditures—a consequence of the utilitarian approach. However, the level of targeted expenditures is relevant for the median voter, as he has to pay for them and does not receive any compensation in return. The higher the initial share of targeted relative to universal expenditures, the sooner the median voter stabilizes, in order to limit redistribution to the poor. Therefore, if the ratio of targeted to universal expenditures is sufficiently high, the median voter votes alongside the wealthiest citizens in order to avoid being expropriated by the poor, preempting redistribution.¹⁶

4 Concluding remarks

This paper brings the majority rule into the realm of economic adjustments and shows that both delays and anticipations may occur—relative to the optimal date of stabilization chosen by a benevolent social planner. Under proportional taxation and universal public expenditures, a modified intertemporal version of the “Meltzer–Richard mechanism” is present in the political equilibrium, resulting in a “redistributive delay.” However, under the more realistic specification where the benefit from public services is concentrated in the poor or the decision power is concentrated among the rich, a “preemptive anticipation” occurs.

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¹⁶This result can be easily related with the literature of targeting—Donder and Hindriks (1998), Moene and Wallerstein (2001b,a) and Gelbach and Pritchett (2002).

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Appendix

Proof of proposition 1

The problem to solve is

$$\max_T U_i(T), \text{ s.t. } T \geq 0$$

where $U_i(T)$ is defined in equation (10). Plugging in the expressions for $g(t)$, $b(t)$ and $b(T)$, using the Fundamental Theorem of Calculus and Leibniz’s rule, and after some tedious algebra that we do not replicate here, it can be shown that

$$\frac{d}{dT}(U_i(T)) = \frac{\gamma}{r}g(T)e^{-rT}[\theta \cdot v'(g(T)) - \varkappa_i]$$

The First Order Condition $\frac{d}{dT}(U_i(T)) \leq 0$ yields the desired solution. To prove that T_i^* is the unique maximizer, it is enough to show that the utility function is strictly quasiconcave, which is straightforward. ■

Proof of proposition 2

Noting that $\int \kappa f_y(y) dy = 1$, the social planner's problem can be written as

$$\begin{aligned} \max_T \quad & \int_0^T \left[-(1 - \alpha)(g(0) + rb(0)) - \alpha(g(t) + rb(t)) + \theta \cdot v(g(t)) \right] e^{-rt} dt \\ & + \int_T^\infty \left[-(g(T) + rb(T)) + \theta \cdot v(g(T)) \right] e^{-rt} dt \\ \text{s.t.} \quad & T \geq 0 \end{aligned}$$

The proof follows exactly the same steps as in proposition one. Our assumption in footnote 9 rules out a corner solution. $g(T_{opt}^*)$ can be obtained by re-arranging equation (12), after observing that $g(T) = g(0) \cdot e^{\gamma T}$. ■