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AGGREGATION AND AGGREGATION

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Abstract
We discuss economic aggregation and political aggregation in the context of a simple dynamic version of the canonical political-economy model—the Meltzer–Richard model. Consumers differ both in labor productivity and initial asset wealth and there is no physical capital. Under commitment over future tax policy, and for economic preferences that imply aggregation in assets and productivity, the induced policy preferences for individuals do not depend on any distributional characteristics other than means. They imply time inconsistency, with taxes changing between the first and the second periods and staying constant thereafter. Political aggregation in the form of a median-voter theorem applies only in special cases. (JEL: D72, D78, E61, H23)

1. Introduction

Beginning in the early 1990s, attempts were made to develop quantitative dynamic frameworks for analyzing policy from a political-economy perspective. The aim was a close parallel to what is now standard in the literature on macroeconomic business cycles: to "account" for the magnitudes and variability of observed policy, using variations in political and economic primitives. An important component here was the representation of relevant aspects of heterogeneity—say, in terms of labor and capital income—so as to capture the source of policy disagreement in a quantitatively reasonable way. There were several roadblocks in this endeavor, however. One was conceptual: How should policy choice over time be modeled? A second was theoretical: Given an equilibrium concept where agents vote over policy, could existence be ensured, and what was the nature of the equilibrium set? Yet a third was numerical: Given a satisfactory notion of a dynamic

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politico-economic equilibrium, how could it be computed? Fourth, and finally, many raised the question of what form policy was assumed to take: Was it not supposed to be derived endogenously and optimally? To date, though progress has been made, no definite answer has been given to any of these questions. The purpose of the present article is to make some progress on some of these questions.

Relative to the literature, we take a step back: we consider a model without capital, and we assume that the government can commit to future tax rates. Our specification allows several precise statements to be made: We can, under additional (but natural) assumptions on preferences, characterize time-zero voting equilibria completely. Thus, we can describe the evolution of asset inequality as well as policy and interest rates precisely, and we can discuss the relation between economic and political aggregation. We are able to map the choice over infinite sequences of tax rates in a standard Ramsey model into a two-dimensional problem resembling the reduced-form policy preference models commonly used in formal political theory. This enables us to use existing insights about existence of median-voter equilibria in an infinite-horizon setting where policy preferences are derived from first principles: preferences, technology, and economic and political institutions. Finally, and perhaps most importantly, our analysis of the dynamics of taxation clarifies how time inconsistency of the commitment outcome emerges, thus giving important background for the more analytically demanding analysis of dynamic political economy without government commitment.

Specifically, we look at a dynamic version of Meltzer and Richard's (1981) model without capital. Consumers can trade intertemporally in an asset market; the economy is closed, and the equilibrium determines the interest rate. Consumers potentially differ in two dimensions: They have different initial asset holdings and they have different labor productivity. Policy amounts to a proportional tax on labor income and a lump-sum transfer subject to period-by-period budget balance. Intuitively, the taxation of labor income has two effects that both imply some form of redistribution: First, it redistributes between consumers with different amounts of labor income (because they have different productivity or because, if there are differences in wealth and there is a wealth effect on labor supply, they work different amount of hours); and second, to the extent taxation varies over time, it influences the rate of interest, which affects consumers with different wealth differently.

We show that for a general class of utility functions, if dictatorial power is given to any agent to determine an infinite policy sequence at time 0 (a "commitment equilibrium") this sequence will feature a constant tax-transfer from the second period and on. Thus, our fully dynamic economy reduces to a two-dimensional policy choice: the tax rate at zero and the tax rate thereafter. If there is no initial asset heterogeneity—a repeated version of the Meltzer–Richard

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model—and preferences admit aggregation, there is also (median-voter) political aggregation; moreover, the tax transfer will be constant from time zero and on and the commitment equilibrium will be time-consistent. In contrast, if there is asset heterogeneity but no heterogeneity in labor productivity, then the commitment equilibrium is time-inconsistent; if, moreover, preferences admit aggregation, taxes will be zero from the second period and on. In the latter case, there is political aggregation as well, and a median-voter theorem applies. With two-dimensional heterogeneity and preferences that admit aggregation (over both assets and productivity differences), the induced policy preferences over the two tax rates can be derived independently of the distribution of types, but political aggregation—say, a median-voter theorem—typically does not obtain.

The previous literature extending Meltzer and Richard (1981) to dynamic settings includes Krusell and Ríos-Rull (1999), which considers a model like the one presented here but with a neoclassical capital-accumulation technology. There, the sole focus is on Markov-perfect equilibria, and a one-period implementation lag for policy is employed. An intermediate case between that paper and the present one is Azzimonti, de Francisco, and Krusell (2006), which focuses on the role of economic aggregation when there is capital accumulation but no commitment. Finally, Azzimonti, de Francisco, and Krusell (forthcoming) study the special case of the present model without heterogeneity in productivity both with and without commitment.[1]

2. Environment

In this infinite horizon economy there is no uncertainty and time is discrete. Agents value consumption, c, and leisure, l, and discount the future at rate β:

$$\sum_{t=0}^{\infty} \beta^t u(c_t, l_t). \tag{1}$$

Agents can trade one-period bonds (which are in zero net supply), each promising one unit of consumption next period. The heterogeneity within the population enters in two ways: (i) through differences in consumers' initial asset holdings, a_0; and (ii) through labor-productivity differences, θ.

An agent is identified by a pair (a_0, θ), which is drawn at the beginning of life from a distribution $F(a_0, \theta)$ with finite support. We denote the conditional

1. Bassetto (1999) considers a setup that is closely related to ours, though without the redistribution mechanism through transfers that is central in our study. Moreover, his main interest is in a case where one agent does not have labor income; thus, this agent is not directly affected by taxation. He also does not impose a period-by-period balanced government budget.

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expectations $E(a_0 \mid \theta) = \bar{a}$ and $E(\theta \mid a_0) = \bar{\theta}$ and the measure of each type with μ^i for $i = \{1, \ldots, I\}$. Population size is normalized to one: $\sum_i \mu^i = 1$.

Production takes place according to a stationary production function that depends linearly on labor. Output is used for consumption and there is no government consumption or investment. We also abstract from capital entirely. Each consumer has one unit of time, so $1 - l^i$ denotes the number of hours worked. We make assumptions on primitives so that agents' decision problems are strictly concave; hence, identical agents will make identical decisions.

3. Equilibrium and Economic Aggregation

There are two prices determined in equilibrium: the price of one-period bonds, denoted by q_t, and the wage rate, w_t, both measured in terms of consumption goods in the same period. In addition, there is a government that taxes labor income at a proportional rate τ_t in period t and makes equal lump-sum transfers T_t back to all consumers under a balanced budget. Thus, a typical consumer budget constraint in period t reads

$$c_t^i + q_t a_{t+1}^i = a_t^i + \theta^i w_t \left(1 - l_t^i\right)(1 - \tau_t) + T_t. \tag{2}$$

In equilibrium, consumers' holdings of assets have to add to zero: $\sum_i \mu_i a_t^i = 0$, where a_t^i denotes the total holdings of agents of type i. We define a competitive equilibrium for a given sequence of government policy as follows.

DEFINITION 1. Given a tax policy $\{\tau_t\}_{t=0}^{\infty}$, a *competitive equilibrium* is a sequence $\{w_t, q_t\}_{t=0}^{\infty}$ of prices together with a sequence $\{\{c_t^i, a_{t+1}^i, l_t^i\}_{i=1}^{I}, T_t\}_{t=0}^{\infty}$ of allocations satisfying the following conditions:

1. for all i, $\{c_t^i, a_{t+1}^i, l_t^i\}_{t=0}^{\infty}$ maximizes (1), subject to equation (2) for all $t \geq 0$, with $a_0 = A_{i0}$;
2. for all $t \geq 0$, $w_t = 1$ and q_t is such that $\sum_i \mu^i a_t^i = 0$; and
3. for all $t \geq 0$, $T_t = \tau_t \sum_i \mu^i \theta^i (1 - l_t^i)$.

We will (implicitly) use preferences and constraints giving interior solutions for all agents. Agent i will choose assets and leisure so that

$$u_c\left(c_t^i, l_t^i\right) w_t \theta^i (1 - \tau_t) = u_l\left(c_t^i, l_t^i\right), \tag{3}$$

$$q_t u_c\left(c_t^i, l_t^i\right) = \beta u_c\left(c_{t+1}^i, l_{t+1}^i\right). \tag{4}$$

Together with the budget constraints and a transversality condition, these conditions are sufficient for finding optimal consumer choices. In general, aggregate allocations and prices depend on the joint distribution of asset holdings and productivity levels, $F(a_0, \theta)$. Under some additional assumptions on preferences it

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is possible to show that prices and aggregate consumption and labor (measured in efficiency units) depend on only two moments: *average asset holdings* (zero, in equilibrium) and *average productivity*, $\bar{\theta}$. Because the ratio between consumption and leisure of any individual becomes linear in productivity θ it is straightforward to verify the following proposition.

PROPOSITION 1. *Under constant relative rule average (CRRA) utility functions,* $[g(c,l)^{1-\sigma}-1]/(1-\sigma)$, *with* $g(c,l)=c^{\alpha}l^{1-\alpha}$ *and* $\alpha,\sigma>0$, *the competitive equilibrium exhibits aggregation: Prices and aggregate consumption and labor (measured in efficiency units) depend on only the first moments of the distribution over assets and labor productivity.*

Under logarithmic utility the competitive equilibrium can be fully characterized in closed form, as stated in the following corollary.

COROLLARY 1. *When* $\sigma=1$, *so* $u(c,l)=\alpha\ln c+(1-\alpha)\ln l$, *the competitive equilibrium can be characterized by the following allocations and prices:*

$$\bar{C}_t=\bar{\theta}\alpha\frac{1-\tau_t}{1-\alpha\tau_t},\quad l_t^i=\frac{(1-\alpha)c_t^i}{\alpha\theta^i(1-\tau_t)},$$
$$c_t^i=\gamma(\tau,\theta^i)\bar{C}_t,\quad q_t=\beta\frac{1-\tau_t}{1-\alpha\tau_t}\frac{1-\alpha\tau_{t+1}}{1-\tau_{t+1}},$$

where

$$\gamma(\tau,\theta^i)=\frac{1}{\bar{\theta}}\left[\frac{1-\alpha\tau_0}{1-\tau_0}a_0^i(1-\beta)+\theta^i+(1-\beta)\alpha\sum_t\beta^t\tau_t(\bar{\theta}-\theta^i)\right].$$

When consumers differ only in initial asset holdings (so that all agents have the same productivity), more general aggregation results can be derived. For example, Azzimonti, de Francisco and Krusell (forthcoming) show that aggregation, in the sense just defined, holds for any homogeneous-of-degree-one function $g(c,l)$, such as the CES function $(\alpha c^{\rho}+(1-\alpha)l^{\rho})^{1/\rho}$. It is also possible to obtain aggregation results where prices and aggregate quantities depend on a small set of other moments of the distribution (see, e.g., Correia 2006).

4. Optimal Policy under Commitment

We now describe agents' preferences over a tax sequence assuming that individuals vote over the whole sequence at period zero. That is, the government can

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commit to implementing policy in the future. We consider Ramsey equilibria, meaning that any feasible policy must be consistent with competitive equilibrium allocations. Before looking at voting equilibria, we study the time-zero tax sequence choice made by an arbitrary consumer i^*.

DEFINITION 2. The tax sequence $\{\tau_t\}_{t=0}^{\infty}$ preferred by agent i^* in a *Ramsey equilibrium* is the one that maximizes the lifetime utility as given by (1) for $i = i^*$ subject to (a) the set of budget constraints, namely, equation (2), for all $t \geq 0$ and all i; (b) the set of optimality conditions for leisure and for asset holdings, namely, equations (3) and (4), respectively, for all $t \geq 0$ and all i; and (c) the market-clearing conditions 2–4 in Definition 1 (see equation (A.1) in the Appendix for more details).

The resulting maximization problem is not, in general, globally a convex problem. For the remaining discussion, however, we will presume that our primitives are such that it is; in particular, we will presume that first-order conditions are sufficient. In the next proposition, proved in the Appendix, we characterize the resulting time structure of taxes preferred by any agent.

PROPOSITION 2. *For any differentiable $u(c, l)$, a first-order characterization for optimal taxes implies that taxes are constant from period $t = 1$ and on. The infinite sequence of taxes preferred by any agent i^* can thus be represented by a tax pair (τ_0^*, τ_1^*) where τ_0^* is the tax rate in period 0 and τ_1^* is the tax rate from period 1 on.*

Thus, our infinite-horizon economy leads to a preferred tax sequence characterized by only two numbers: the tax rate in the first period and the tax rate thereafter. No more than two rates are needed due to the stationarity of the economy and the absence of capital; no less than two rates are needed due to the special role played by the first period, thus illustrating that the commitment solution is not, in general, time-consistent.

5. Characterizing the (τ_0^*, τ_1^*) Pair Using Economic Aggregation

5.1. *Overview*

Under the log-log preferences used in Corollary 1, our aggregation result implies that the representative agent has $a_0 = 0$ and $\theta = \bar{\theta}$. Furthermore, the indirect utility takes a very simple form, and it is independent of other moments of the distribution $F(a_0, \theta)$ than mean ability ($\bar{\theta}$) and average initial asset holdings, which are zero. As a result, the preferred taxes will also be independent

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of the wealth-ability distribution. Agent i^*'s preferred policy sequence is that which maximizes his indirect utility, which in general can be shown to equal

$$V\left(\tau, \theta^{i^*}\right) = \sum_t \beta^t [\alpha \ln(1-\tau_t) - \ln(1-\alpha\tau_t) + \ln \gamma(\tau, \theta^{i^*})],$$

where τ denotes the whole tax sequence; see Corollary 1 for the definition of $\gamma(\tau, \theta^{i^*})$.

As stated in Proposition 2 for a more general case, the necessary conditions reduce to two equations in two unknowns:

$$-\bar{\theta}\gamma(\tau^*, \theta^{i^*})(1-\alpha)\tau_1^* + (\bar{\theta} - \theta^{i^*})\left(1-\tau_1^*\right)\left(1-\alpha\tau_1^*\right) = 0,$$

$$-\bar{\theta}\gamma(\tau^*, \theta^{i^*})(1-\alpha)\tau_0^* + (\bar{\theta} - \theta^{i^*})\left(1-\tau_0^*\right)\left(1-\alpha\tau_0^*\right) + \frac{1-\alpha}{\alpha}\frac{1-\alpha\tau_0^*}{\left(1-\tau_0^*\right)}a_0^{i^*} = 0.$$

As should be expected, the representative agent prefers $\tau_0 = \tau_1 = 0$ (because $\gamma[\tau, \bar{\theta}] = 1$). We will now characterize the solution to this equation system, first looking at special cases and then the general case.

5.2. No Asset Inequality

Without asset heterogeneity the economy collapses to an infinitely repeated version of the one studied by Meltzer and Richard (1981). This case exhibits no interesting dynamics, as the tax sequence preferred by any agent in the economy is time-invariant. The price of one-period bonds must then satisfy $q_t = \beta$: because there is no asset heterogeneity, no agent sees a gain from manipulating q_t by time-varying taxes. It is easy to show that if an agent's productivity is lower (higher) than average, then a tax on (subsidy to) labor is preferred.

5.3. No Skill Inequality

When productivities do not differ but assets do, the analysis (which is contained in Azzimonti, de Francisco, and Krusell forthcoming) shows that there is active interest-rate manipulation, unless i^* is the representative, zero-asset agent. For example, a tax hike at time zero raises consumption growth between the first two periods and thus the interest rate, which helps asset-rich agents. A similar hike in the future raises the corresponding interest rate but also lowers the interest rate one period earlier. Taxes, of course, also directly redistribute to the extent agents with different asset holdings work different hours.

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Under preferences that admit economic aggregation—which, as pointed out previously is now a larger class—this economy has the striking feature that all agents agree on the tax rate from period 1 onwards: it should be zero. A tax hike at t redistributes toward the asset-rich at that date (because they have lower wage income due to a wealth effect on labor supply) but q_{t-1} falls, an effect which operates on all income of the asset-rich, and for this class of preferences these two effects offset exactly. As for τ_0^*, the offsetting interest-rate effect is not present, of course, making the asset-rich prefer positive time-zero taxes.

5.4. The General Case

Although there is no closed-form solution for the two tax rates, it is straightforward to compute them numerically by solving the equation system displayed herein. Figure 1 illustrates optimal policy for different agent types.

The dashed lines depict the preferred τ_1^* values for agents with different a_0 (on the horizontal axis); different dashed lines correspond to different values of θ. Two conclusions emerge: (i) the future tax rate is positive if and only if $\theta < \bar{\theta}$ ($\bar{\theta}$ is normalized to 1 in the figure); and (ii) the future tax rate preferred by agent i^* barely depends on his initial asset holdings at all. In sum, the future tax rate is dictated by Meltzer–Richard arguments, even though there is asset inequality in the economy.

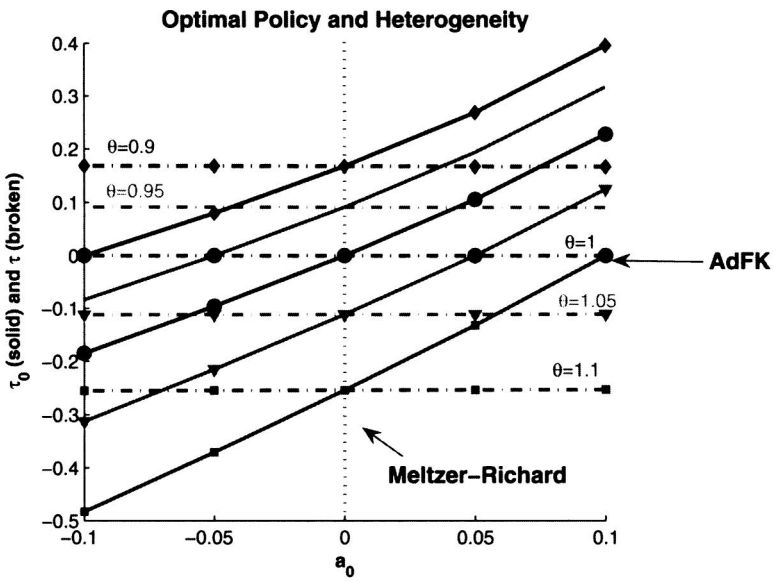

FIGURE 1. Optimal policy for different types.

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As for the time-zero tax rate (τ_0^*), its dependence on a_0 and θ is given by the solid lines. The key conclusion here is that time-zero rates are given by a combination of Meltzer–Richard arguments—more productive agents prefer lower tax rates—and those in Azzimonti, de Francisco, and Krusell (forthcoming): the asset-rich prefer higher tax rates, due to interest-rate effects.

Note, finally, that in the general case, the two first-order conditions are interdependent and the determination of τ_1^* depends on the choice of τ_0^*; reference to this observation will be made later.

6. Political Aggregation

The types of models studied in this article are complex due to the presence of two dynamic-equilibrium layers: the economic and the political one, and a potentially large state space. Theory related to existence, uniqueness, and characterization of a non-empty core for voting rules is scarce, and there are few theorems that apply with generality. We now provide some results for the present model that are based on assuming that economic aggregation obtains.

6.1. One-Dimensional Heterogeneity

Under one-dimensional heterogeneity, either in skills or in assets, political aggregation is simple to obtain: The median voter theorem holds as long as indirect preferences are single-peaked or a single crossing condition applies, which one can verify for classes of preferences. The case with skill heterogeneity only is covered in Meltzer and Richard (1981); the case with asset inequality only also admits a median-voter theorem, as long as preferences admit economic aggregation.[2]

6.2. Two-Dimensional Heterogeneity

Two-dimensional heterogeneity need not pose a problem for political aggregation; see, for example, the analyses in Grandmont (1978) and Persson and Tabellini (2000). However, when there are two policy variables—recall that the induced preferences in our infinite-horizon model are defined over (τ_0, τ_1) here—one needs very strong symmetry assumptions on these induced preferences, which will not generally obtain. That is, the restrictions imposed by the underlying economic model generally do not imply that a core exists. As an illustration, Figure 2 shows the induced indifference curve for tax-rate pairs of an agent with logarithmic utility: it is neither elliptical nor symmetric around its preferred point.

2. See Azzimonti, de Francisco, and Krusell (forthcoming) for the detailed arguments.

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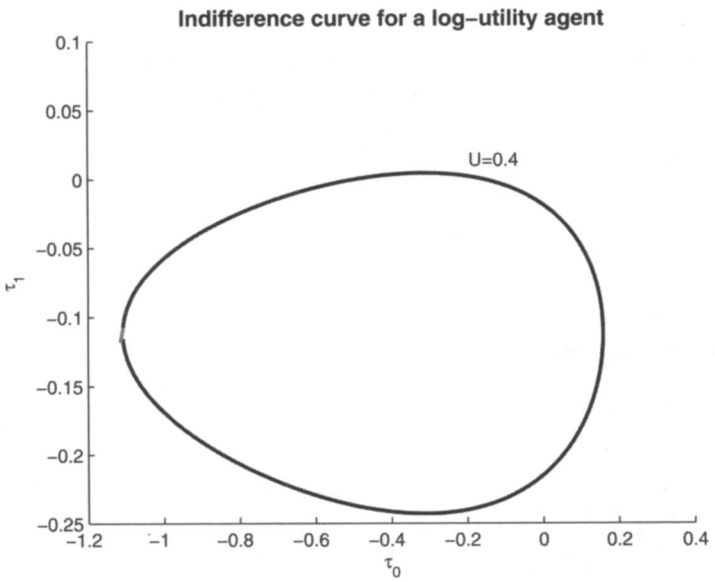

FIGURE 2. The egg.

We will merely make three points here. One is simple: Economic aggregation is still useful, because it makes the induced preferences independent of the asset-productivity distribution. That is, the indifference curves such as those in Figure 2 do not depend on how assets and productivities are distributed and can thus be derived separately.

Second, we will illustrate how a median-voter theorem can be obtained: by placing severe restrictions on the asset and productivity heterogeneity. In general, there is no natural "middle" in the two-dimensional space and any policy can typically be beaten, say, by a majority. So for illustration suppose that utility is logarithmic and that productivity and initial assets each can take on three values: $\theta^i \in \{\bar{\theta} - \varepsilon, \bar{\theta}, \bar{\theta} + \varepsilon\}$ with $\varepsilon > 0$ and $a_0^i \in \{-\delta, 0, \delta\}$ with $\delta > 0$. Thus, there are nine types of agents symmetrically distributed around $a_0 = 0$ and $\bar{\theta} = 1$. The left panel of Figure 3 depicts the implied preferred combination of taxes for each type.

In this example, there is a well-defined median agent in the distribution—the mean agent—and we expect that his preferred policy (zero taxes at all times) will beat any alternative tax pair (τ_0, τ_1) in pairwise voting. To prove this, we can apply Theorem 5.7 in Austen-Smith and Banks (1999) and its corollaries to show that indeed that is the case, as long as the Plott conditions are satisfied (which in this context are necessary and sufficient). These conditions require that for any coalition of agents there must exist a "pairing": if any small deviation from the proposed policy pair benefits one agent, it must be detrimental for another agent.

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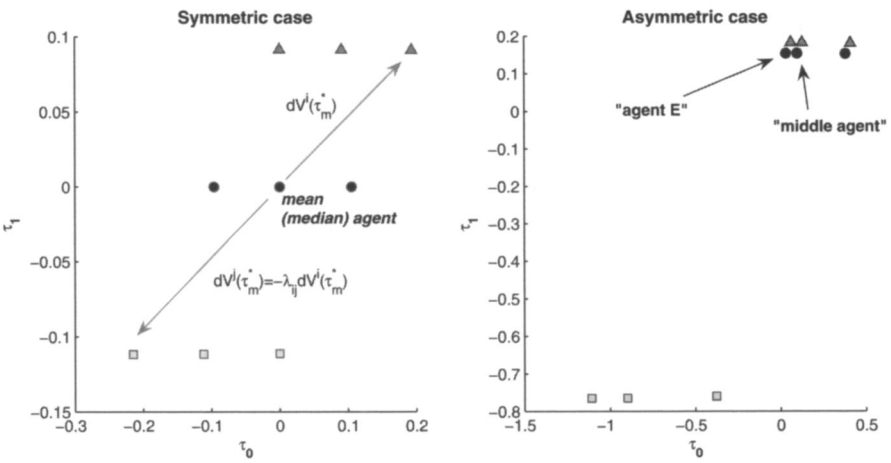

FIGURE 3. Preferred policy under a symmetric distribution of types.

Let the gradient of agent i be denoted by $dV^i(\tau_m^*)$.[3] Mathematically, the condition implies that there must exist a constant λ_{ij} such that $dV^i(\tau_m^*) = -\lambda_{ij} dV^j(\tau_m^*)$ for some λ_{ij}. For example, an agent with $\theta = \bar{\theta}$ and $a_0^i = \delta$ can be paired with an agent with $\theta = \bar{\theta}$ and $a_0^j = -\delta$.[4] One can similarly pair all remaining agents.

In any "asymmetric" case, however, the core typically does not exist. Suppose that the nine types of agents are instead composed by all possible combinations of θ and a_0 where $\theta \in [0.89, 0.91, 1.2]$ and $a_0 \in [-0.07, -0.03, 0.10]$, implying that the agent with $\theta = 0.91$ and $a_0 = -0.03$ would be median in each dimension separately. Now the median agent's preferred policy would be beaten by a policy proposed by agent with the same asset level but lower productivity (agent E in the right panel of Figure 3). This policy would not be a majority-voting equilibrium either, however, because it does not satisfy the Plott conditions: The core is empty in this case.

Third, and finally, the nonexistence of a core does not make political-economy analysis uninteresting in this model, of course. It just means that outcomes depend on the exact nature of the policy games played. Thus, one must specify further details about these games in order for outcomes to be well defined. Then positive as well as normative properties of different games can be examined and compared.

3. Here, $dV(\tau_m^*) = ([\alpha(\bar{\theta} - \theta) + (1 - \alpha)a_0^i]/[a_0^i(1 - \beta) + \theta^i], \alpha(\bar{\theta} - \theta)/[a_0^i(1 - \beta) + \theta^i])$.
4. This means that $\lambda_{ij} = [\bar{\theta} - \delta(1 - \beta)]/[\bar{\theta} + \delta(1 - \beta)]$.

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7. Conclusion

We have discussed economic and political aggregation using a simple dynamic version of the canonical political-economy model—the Meltzer–Richard model—where consumers differ both in productivity and initial wealth. For a general class of preferences, the tax sequence preferred by any agent reduces to a two-dimensional object: a time-zero rate and a rate for all later periods. Under commitment, future taxes are mainly guided by productivity differences (the Meltzer–Richard mechanism), whereas period-zero taxes are influenced also by wealth inequality. The case without commitment is not analyzed here, but in a Markov-perfect equilibrium, all taxes would be affected both by wealth and productivity inequality, and political aggregation would apply more readily; however, much of the analysis of such models is work that lies ahead.

Appendix

Agent i^* solves

$$\begin{aligned}\max \quad & \sum_{t=0}^{\infty} \beta^t \Bigg\{ u(c_t^*, l_t^*) + \sum_i \mu^i \lambda_{t1}^i \Big[- c_t^i + a_t^i - q_t a_{t+1}^i \\ & + \theta^i w_t (1 - l_t^i)(1 - \tau_t) + \tau_t \sum_j \mu^j \theta^j (1 - l_t^j) \Big] \\ & + \sum_i \mu^i \lambda_{t2}^i \big[u_c(c_t^i, l_t^i) w_t \theta^i (1 - \tau_t) - u_l(c_t^i, l_t^i) \big] \\ & + \sum_i \mu^i \lambda_{t3}^i \big[q_t u_c(c_t^i, l_t^i) - \beta u_c(c_{t+1}^i, l_{t+1}^i) \big] \\ & + \lambda_{t4} \Big[\sum_j \mu^j \theta^j (1 - l_t^j) - \sum_j \mu^j c_t^j \Big] \Bigg\}. \end{aligned} \tag{A.1}$$

The first-order conditions (FOCs), with $I_i = 0 \forall i \neq i^*$ and where $\lambda_{t-1,3}^i = 0$ for $t = 0$, are

$$I_i \frac{u_{c_t}^i}{\mu^i} - \lambda_{t1}^i + \lambda_{t2}^i \big[u_{cc_t}^i \theta^i (1 - \tau_t) - u_{lc_t}^i \big] + u_{cc_t} \big(\lambda_{t3}^i q_t - \lambda_{t-1,3}^i \big) - \lambda_{t4} = 0 \qquad (c_t^i)$$

$$I_i \frac{u_{l_t}^i}{\mu^i} - \lambda_{t1}^i \theta^i (1 - \tau_t) - \tau_t \theta^i \sum_j \mu^j \lambda_{t1}^j + \lambda_{t2}^i \big[u_{cl_t}^i \theta^i (1 - \tau_t) - u_{ll_t}^i \big] + u_{cl_t} \big(\lambda_{t3}^i q_t - \lambda_{t-1,3}^i \big) - \lambda_{t4} \theta^i = 0 \qquad (l_t^i)$$

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$$\lambda^i_{t1} q_t - \lambda^i_{t+1,1}\beta = 0 \quad (a^i_{t+1})$$

$$-\sum_j \lambda^j_{t1}\mu^j a^j_{t+1} + \sum_j \lambda^j_{t3}\mu^j u^j_{c_t} = 0 \quad (q_t)$$

$$-\sum_i \lambda^i_{t1}\mu^i\theta^i\left(1-l^i_t\right) + \left[\sum_j \mu^j\theta^j(1-l^j_t)\right]\sum_i \mu^i\lambda^i_{t1} - \sum_i \lambda^i_{t2}\mu^i u^i_{c_t}\theta^i = 0 \quad (\tau_t)$$

We need to show that policy can be summarized by (τ_0, τ_1) and allocations, prices, and multipliers that are constant from $t \geq 1$. The unknowns are: $6I$ multipliers from individual choices, $\{\lambda^i_{t1}, \lambda^i_{t2}, \lambda^i_{t3}\}_{it}$ for $t = 0, 1$; 2 multipliers from market-clearing conditions, $(\lambda_{04}, \lambda_{14})$; $5I$ individual allocations $\{c^i_t, l^i_t, a^i_1\}_{it}$; 2 prices (q_0, q_1); and 2 tax levels (τ_0, τ_1). There are a total of $11I + 6$ unknowns. Under the guess, the equations at $t > 1$ are the same (to be verified later). The FOCs at 0 and 1 are different because (a) they involve initial conditions, a^i_0, and (b) the FOCs for c^i_t and l^i_t involve multipliers in the previous periods (i.e., $\lambda_{t-1,3}$). For periods 0 and 1, there are $6I + 2$ FOCs for the multipliers, 2 for prices, 2 for taxes and $6I$ for individual allocations, totalling $12I + 6$ equations. Under the guess, c^i_t is constant and $q_t = \beta$ for $t \geq 1$, so I FOCs for λ^i_{13} cancel out (those involving the a^i_2 choices). This leaves $5I + 2$ linearly independent equations that can be used to solve for competitive allocations and prices ($5I + 2$ unknowns). Given these, we can find $6I + 2$ multipliers and 2 tax levels from the remaining equations (a total of $6I + 4$ unknowns). $5I + 4$ independent equations follow from the FOCs for allocations, policies, and prices (the FOC for a^i_2 does not add new information under the guess). We are missing I equations to complete the system. Also, we need to ensure that the future FOCs are met under the guess. Notice that the FOCs for c^i_2 and for c^i_1 are almost the same, with the exception being the term involving $\lambda^i_{t-1,3}$: The latter includes λ^i_{03} and the former does not (only λ^i_{13} is present). Thus, if we include an extra set of restrictions, $\lambda^i_{03} = \lambda^i_{13}$ for all, the two FOCs are identical under the guess. These additional I independent equations complete the system. The leisure FOCs in the two periods, which also involve $\lambda^i_{t-1,3}$, are now identical under the guess. Lastly, it is easy to see that all future optimality conditions are met.

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