Online Appendix to
"Public Debt and Fiscal Competition"

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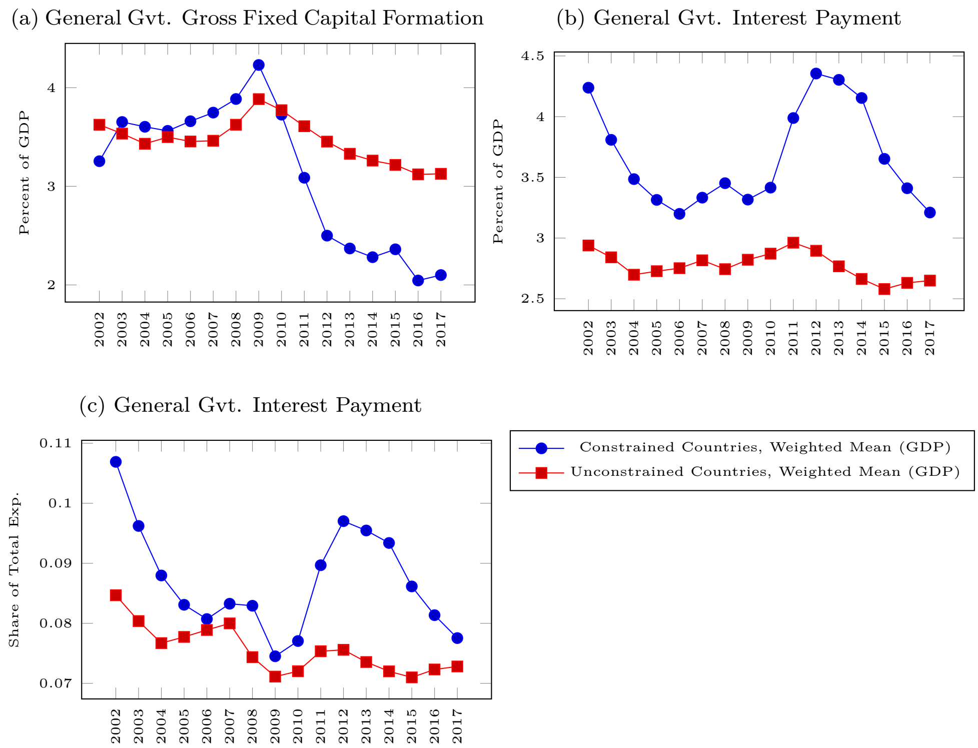
Online Appendix B: Additional Empirical Material

B.1 The Economic and Financial Crisis 2008: Additional Data

Figure 1: Public Debt, Public Investment and Taxation



B.2 Event-Study Design

B.2.1 Empirical Specification

We apply an event study design and estimate the response of two fiscal policy instruments to shocks in the debt-repayment burden of individual municipalities. The latter are defined as years in which the level of net redemption payments of a municipality is extraordinarily high. Net redemption payments are defined as the difference between the total debt redemption payment and additional revenue obtained from issuing new debt in the same period. We set the value of net redemption payments to zero whenever newly issued credit exceeds redemption payments.[1] We then compute the share of net redemption payments in the net expenditure of a municipality for each individual year and also the average of this share within a municipality across the observation period. A shock is defined as a municipal-year observation in which the share is at least three times as high as its average within the municipality. Our empirical model takes the following form:

$$y_{i,t} = \sum_{n=-4}^{5} \alpha_n s_{i,t-n} + \boldsymbol{\beta_2 x_{i,t}} + \boldsymbol{\psi} + \epsilon_{i,t}. \tag{B.1}$$

$y_{i,t}$ is the fiscal policy variable of interest in municipality i at year t, and $s_{i,t}$ is a dummy that indicates whether in year t municipality i experienced a debt repayment shock as described above. Within the first and last year in our sample, 1998 and 2012, we define an event window of 10 years, that is, we observe 4 years before and 5 years after the repayment shock as well as the shock year itself.[2] In each year, we thus compare the treated municipalities to those that did not experience a debt repayment shock in this particular period. Following Kline (2012) we adjust the end points of the event window to indicate whether a debt repayment shock has occurred 4 or more years before (upper window limit) and 5 or more years after a given year (lower window limit) in order to mitigate collinearity with the year-fixed effects. The resulting coefficients, however, do not assign the same weights to municipalities with events early and late in our observation period since the sample is generally unbalanced in event time. As in Kline (2012), the interpretation of the results thus focuses on the coefficients for indicators within the event window. To avoid perfect collinearity among the shock indicators, the regressor in the year before the repayment shock is dropped and normalized to zero. As a consequence, the remaining coefficients α_t are interpreted as the effect of the shock on $y_{i,t}$ relative to the pre-shock year. We complement our model by a vector of control variables, $\boldsymbol{x_{i,t}}$, including the logarithm of total population and the logarithm of GDP per capita in the district of the municipality. Furthermore, we intend to capture unobserved confounding factors by including a set of fixed effects which comprises municipality-fixed effects, year-fixed effects and state-year-fixed effects. The latter take into account that time trends may vary across states (*Länder*).

[1] This avoids classifying temporary reductions of municipal borrowing with a continuing increase in public debt as debt repayment shocks.

[2] Expanding or contracting the event window by up to 2 years leads to virtually the same results.

Since our fiscal competition model relies on the interaction between competing jurisdictions, we are not only interested in the response of the municipality that experiences the debt repayment shock but also in the response of its competing neighbors. We therefore rerun the model described above in a separate regression replacing the variables $y_{i,t}$ and $\boldsymbol{x_{i,t}}$ with the weighted average of the respective variables across the neighboring municipalities that are located within 10 kilometers of municipality i. Using inverse distance weights in terms of the difference in total population between the municipality and its neighbor[3], we observe how fiscal policy evolves in the neighboring jurisdictions of a municipality that experiences a debt repayment shock. The effect is identified by comparing the neighbors of treated and untreated municipalities in each year. Note that the control group includes the whole sample in both regressions.

B.2.2 Data

Table B.1: Summary Statistics: Municipalities

Variable	Observations	Mean	Standard deviation	Min	Max
Business Tax Rate	165,873	14.880	2.698	0	45
Property Tax Rate	165,878	1.451	0.670	0	4.55
Log Local Public Investment Expenditure	151,360	12.819	2.071	1.138	20.416
Shock ($s_{i,t}$)	165,880	0.054	0.225	0	1
Log GDP p.c.	121,985	10.075	0.227	9.484	11.580
Log Population	165,880	7.568	1.491	1.099	15.073

The data set contains information on fiscal variables, including local tax rates, of all municipalities in Germany from 1998 to 2012. The full set of descriptive statistics can be found in Table B.1. In total, there are 11,064 municipalities in our sample. The effective business tax rates are obtained by multiplying the base rate ("Steuermesszahl") of 3.5% (5% until 2007) with the local tax rate ("Hebesatz"), which is determined each year by the municipal council. The base rates are determined at the federal level and are therefore not a local choice variable. The effective business tax rates in our sample range from 0% to 45% with an average of 14.9%. About 17.2% of municipalities change their local business tax rate within the sample period.

The distribution of debt repayments that are used to define debt repayment shocks is displayed in Table B.2. We report the distribution with and without negative values normalized to zero. While the mean of the censored sample is substantially below the uncensored mean, there is only a small difference in the median, indicating a relatively stable distribution. During the sample period, 57.5% of the municipalities in our sample experience

[3]In an untabulated robustness check we have used distance weights in terms of geographical distance in kilometers and obtained very similar outcomes. Results are available from the authors upon request.

a debt repayment shock that is computed as described above. Only 3.5% of municipalities

Table B.2: Distribution of Debt Repayments

	Variable	Mean	SD	Min	Median	Max
(1)	Net redemption payments in th EUR	16.03	5,884.13	-678,588.03	12.09	758,959.82
(2)	Net redemption payments in th EUR (negative payments set to zero)	228.68	4,822.40	0.00	7.17	758,959.82
(3)	Share of net redemption payments in the net expenditure	0.03	0.10	0.00	0.01	26.90
(4)	Avg. share of net redemption payments in the net expenditure within municipality	0.03	0.05	0.00	0.02	2.44
(5)	Ratio of (4) and (5)	1.00	1.46	0.00	0.65	15.00

have more than two shocks. The empirical framework described above accounts for the occurrence of more than one event within a unit.

B.2.3 Results

In the main text, we present and discuss our results in the form of event-study graphs. Here, we display the coefficient estimates of the corresponding regressions in Table B.3. Furthermore, we estimate reaction functions in the spirit of Brueckner & Saavedra (2001)

Table B.3: Event Study: Regression Results

This table contains the regression results of the event study design. All regressions contain year, municipality and state-year fixed effects. The dependent variable is the logarithm of public investment expenditure in columns (1)-(2) and the local business tax rate in columns (3)-(4). In columns (2) and (4), the dependent variable and the control variables refer to the corresponding inverse distance weighted average (weighted according to difference in population) of all neighboring municipalities of municipality within 10km. Cluster robust standard errors (clustered at the municipality level) are provided in parentheses. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

	Public Investment Expenditure		Business Tax Rate	
	(1) Treated	(2) Neighbor	(3) Treated	(4) Neighbor
$s_{i,t+4}$	0.031**	-0.016	-0.023**	0.005
	(0.015)	(0.011)	(0.010)	(0.008)
$s_{i,t+3}$	0.115***	-0.015	-0.012*	-0.009
	(0.017)	(0.012)	(0.007)	(0.006)
$s_{i,t+2}$	0.107***	-0.011	-0.005	-0.006
	(0.014)	(0.010)	(0.005)	(0.005)
$s_{i,t}$	-0.268***	-0.009	-0.007	0.011***
	(0.013)	(0.010)	(0.005)	(0.004)
$s_{i,t-1}$	-0.106***	-0.012 (0.011)	-0.016***	0.015***
	(0.016)	(0.006)	(0.006)	(0.006)
$s_{i,t-2}$	-0.036**	-0.008	-0.020***	0.018***
	(0.017)	(0.012)	(0.007)	(0.007)
$s_{i,t-3}$	-0.021	-0.001	-0.020**	0.016**
	(0.017)	(0.012)	(0.009)	(0.008)
$s_{i,t-4}$	-0.010	0.009	-0.022**	0.018**
	(0.018)	(0.013)	(0.013)	(0.009)
$s_{i,t-5}$	-0.022	-0.015	-0.039***	0.011
	(0.015)	(0.011)	(0.011)	(0.010)
Log GDP p.c.	0.404***	0.269***	-0.123*	-0.141***
	(0.091)	(0.083)	(0.072)	(0.044)
Log Population	0.106	1.107***	-0.206**	0.144
	(0.133)	(0.071)	(0.102)	(0.118)
Observations	116,463	103,103	121,985	104,666
Municipalities	8,132	6,979	8,137	6,981
R^2	0.110	0.206	0.957	0.972

which are presented in Table B.4. In an additional robustness check, we follow Foremny & Riedel (2014) and augment the event-study design by several political economy variables. We include the share of left-leaning parties (SPD, Greens, Left) and right-leaning parties (CDU/CSU, FDP) in the local council of a municipality as well as an indicator for local

Table B.4: Reaction Functions

This table contains the regression results of fixed effects model with the local business tax rate and the logarithm of public infrastructure investments as the dependent variable in columns (1) and (2) respectively. The average local business tax and the average investment expenditure of the neighbors is computed using the average of the corresponding variables in the municipalities within 10 km of the observed jurisdictions (weighted according to difference in population). All regressions contain year, municipality and state-year fixed effects. Cluster robust standard errors (clustered at the municipality level) are provided in parentheses. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

	Business Tax Rate (1)	Public Investment Expenditure (2)
Avg. Local Business Tax of Neighbors	0.236***	
	(0.014)	
Avg. Log Investment Expenditure of Neighbors		0.060***
		(0.008)
Log GDP p.c.	-0.016	0.356***
	(0.072)	(0.106)
Log Population	-0.136	-0.063
	(0.101)	(0.153)
Election	0.210	0.406
	(0.387)	(0.970)
Share Right	0.063	0.072
	(0.053)	(0.084)
Share Left	-0.001	-0.134
	(0.066)	(0.109)
Observations	96,427	92,308
Municipalities	6,891	6,886
R^2	0.965	0.100

elections. Results presented in Table B.5 are similar to the benchmark estimation and suggest, that these political economy factors do not drive our results. Since several highly

Table B.5: Event Study: Political Economy Variables

This table contains the regression results of the event study design. All regressions contain year, municipality and state-year fixed effects. The dependent variable is the logarithm of public investment expenditure in columns (1)-(2) and the local business tax rate in columns (3)-(4). In columns (2) and (4), the dependent variable and the control variables refer to the corresponding inverse distance weighted average (weighted according to difference in population) of all neighboring municipalities of municipality within 10km. Cluster robust standard errors (clustered at the municipality level) are provided in parentheses. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

	Public Investment Expenditure		Business Tax Rate	
	(1) Treated	(2) Neighbor	(3) Treated	(4) Neighbor
$s_{i,t+4}$	0.031**	-0.016	-0.024**	0.005
	(0.015)	(0.011)	(0.010)	(0.008)
$s_{i,t+3}$	0.115***	-0.015	-0.012*	-0.009
	(0.017)	(0.012)	(0.007)	(0.006)
$s_{i,t+2}$	0.107***	-0.011	-0.005	-0.006
	(0.014)	(0.010)	(0.005)	(0.005)
$s_{i,t}$	-0.269***	-0.010	-0.007	0.011***
	(0.013)	(0.010)	(0.005)	(0.004)
$s_{i,t-1}$	-0.108***	-0.013	-0.016**	0.015***
	(0.016)	(0.011)	(0.006)	(0.006)
$s_{i,t-2}$	-0.038**	-0.009	-0.019**	0.019***
	(0.017)	(0.012)	(0.007)	(0.007)
$s_{i,t-3}$	-0.024	-0.003	-0.019**	0.016**
	(0.017)	(0.012)	(0.009)	(0.008)
$s_{i,t-4}$	-0.012	0.006	-0.020**	0.019**
	(0.018)	(0.013)	(0.010)	(0.009)
$s_{i,t-5}$	-0.024	-0.015	-0.037***	0.012
	(0.015)	(0.011)	(0.011)	(0.010)
Log GDP p.c.	0.387***	0.268***	-0.138*	-0.140***
	(0.091)	(0.082)	(0.071)	(0.044)
Log Population	0.096	1.099***	-0.212**	0.153
	(0.127)	(0.071)	(0.098)	(0.118)
Election	0.339	-0.105	-0.080	0.078
	(0.534)	(0.409)	(0.280)	(0.108)
Share Right	0.070	0.042	0.087	-0.078*
	(0.078)	(0.062)	(0.056)	(0.046)
Share Left	-0.156	-0.153**	-0.077	0.004
	(0.102)	(0.067)	(0.072)	(0.055)
Observations	116,120	102,791	121,505	104,351
Municipalities	8,102	6,958	8,105	6,960
R^2	0.111	0.205	0.958	0.972

indebted municipalities in Germany have eliminated their debt burden by selling municipal assets such as real estate to repay outstanding debt, one might be concerned that these events drive our results. In particular, the reduction in the stock of public capital induced by the asset sales might have also triggered the subsequent decrease in public investment. We ensure that this is not the case by repeating the analysis excluding all municipalities involved in substantial real estate privatizations during the observation period. Information for this exercise has been provided by the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR). We obtain virtually the same results (displayed in Table B.6) when excluding these municipalities.

Table B.6: Event Study: Excluding Public Real Estate Sales

This table contains the regression results of the event study design. Municipalities that, according to the Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR), underwent a substantial real estate privatization during the observation period are excluded from the sample. All regressions contain year, municipality and state-year fixed effects. The dependent variable is the logarithm of public investment expenditure in columns (1)-(2) and the local business tax rate in columns (3)-(4). In columns (2) and (4), the dependent variable and the control variables refer to the corresponding inverse distance weighted average (weighted according to difference in population) of all neighboring municipalities of municipality within 10km. Cluster robust standard errors (clustered at the municipality level) are provided in parentheses. Stars behind coefficients indicate the significance level, * 10%, ** 5%, *** 1%.

	Public Investment Expenditure		Business Tax Rate	
	(1) Treated	(2) Neighbor	(3) Treated	(4) Neighbor
$s_{i,t+4}$	0.032**	-0.016	-0.024**	0.005
	(0.015)	(0.011)	(0.009)	(0.008)
$s_{i,t+3}$	0.115***	-0.016	-0.011*	-0.009
	(0.017)	(0.012)	(0.007)	(0.006)
$s_{i,t+2}$	0.107***	-0.012	-0.005	-0.006
	(0.014)	(0.010)	(0.005)	(0.005)
$s_{i,t}$	-0.269***	-0.010	-0.007	0.011***
	(0.013)	(0.010)	(0.005)	(0.004)
$s_{i,t-1}$	-0.106***	-0.012	-0.015**	0.015***
	(0.016)	(0.011)	(0.006)	(0.006)
$s_{i,t-2}$	-0.035**	-0.008	-0.019***	0.018***
	(0.017)	(0.012)	(0.007)	(0.007)
$s_{i,t-3}$	-0.019	-0.001	-0.019**	0.015**
	(0.017)	(0.012)	(0.009)	(0.008)
$s_{i,t-4}$	-0.009	0.008	-0.020**	0.018**
	(0.018)	(0.013)	(0.010)	(0.009)
$s_{i,t-5}$	-0.021	-0.015	-0.038***	0.012
	(0.016)	(0.011)	(0.011)	(0.010)
Log GDP p.c.	0.406***	0.270***	-0.151**	-0.141***
	(0.091)	(0.083)	(0.072)	(0.044)
Log Population	0.110	1.109***	-0.192*	0.144
	(0.133)	(0.071)	(0.102)	(0.118)
Observations	116,205	102,977	121,673	104,531
Municipalities	8,112	6,970	8,116	6,972
R^2	0.111	0.206	0.957	0.972

B.3 Numerical Example

The numerical analysis is conducted for quasi-linear utility functions with $h_{i1}(x) = \ln(x)$ and $h_{i2}(x) = x$. The investment cost function is quadratic, $c(m_i) = m_i^2$. We set $\rho = 1.4$, $\nu = 1.4$, $\gamma = 1.3$, $\delta = 1$, $z = 0.25$, $r = 0.01$ such that $\beta = 0.99$ and $b^{wtp} = 0.19$. We solve the model using a simple iterative algorithm. In a first step, we compute the equilibrium with symmetric initial infrastructure levels ($\bar{q}_i = \bar{q}_j$). Solutions for the key variables are displayed in Table B.7. In a second step, we introduce a positive relation between legacy debt and initial infrastructure installments by assuming that $\bar{q}_i = \epsilon b_{i0}$. The depreciation rate is $\delta = 0.5$. All other parameters and functional form specifications remain as above. Results for different levels of ϵ are presented in Table B.8.

Table B.7: Numerical Solution

		Case I		Case II		Symmetry	
	Jurisdiction	1	2	1	2	1	2
Borrowing Constraint		No	No	Yes	No	Yes	Yes
Debt	b_{i0}	0.060	0.050	0.150	0.050	0.150	0.100
	b_{i1}^{des}	0.183	0.173	0.265	0.174	0.265	0.221
	b^{wtp}	0.200	0.200	0.200	0.200	0.200	0.200
Period 1	b_{i1}^{*}	0.183	0.173	0.200	0.174	0.200	0.200
	m_i^{*}	0.231	0.231	0.210	0.233	0.210	0.226
	τ_{i1}^{*}	0.631	0.631	0.631	0.631	0.631	0.631
	N_{i1}^{*}	0.500	0.500	0.500	0.500	0.500	0.500
	g_{i1}^{*}	0.385	0.385	0.320	0.385	0.320	0.363
Period 2	τ_{i2}^{*}	0.631	0.631	0.620	0.641	0.624	0.638
	N_{i2}^{*}	0.500	0.500	0.496	0.504	0.497	0.503
	g_{i2}^{*}	0.130	0.141	0.106	0.148	0.108	0.119

Table B.8: Numerical Solution for Asymmetric Initial Public Infrastructure

		$\epsilon = 0.1$				$\epsilon = 0.3$		$\epsilon = 2$	
		Case I		Case II		Case II		Case II	
	Jurisdiction	1	2	1	2	1	2	1	2
Borrowing Constraint		No	No	Yes	Yes	Yes	Yes	Yes	Yes
Debt	b_{i0}	0.060	0.050	0.150	0.050	0.150	0.050	0.150	0.050
	b_{i1}^{des}	0.183	0.173	0.266	0.174	0.267	0.173	0.281	0.169
	b^{wtp}	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
Period 1	b_{i1}^{*}	0.183	0.173	0.200	0.174	0.200	0.173	0.200	0.169
	m_i^{*}	0.231	0.231	0.212	0.232	0.215	0.231	0.245	0.222
	τ_{i1}^{*}	0.631	0.630	0.635	0.626	0.645	0.617	0.724	0.537
	N_{i1}^{*}	0.500	0.500	0.502	0.498	0.505	0.495	0.533	0.467
	g_{i1}^{*}	0.385	0.384	0.323	0.381	0.328	0.375	0.375	0.320
Period 2	τ_{i2}^{*}	0.631	0.631	0.624	0.638	0.630	0.631	0.689	0.573
	N_{i2}^{*}	0.500	0.500	0.497	0.503	0.500	0.500	0.521	0.479
	g_{i2}^{*}	0.131	0.140	0.108	0.145	0.113	0.141	0.157	0.104

Online Appendix C: Additional Derivations

C.1 An Endogenous Constraint on Public Borrowing through Default on Government Debt

In the base model we assumed that there is an exogenous limit on debt when borrowing is constrained. We now consider default on debt in period 2 through a willingness-to-pay constraint, which allows us to derive the borrowing constraint from a default problem. A government honors the debt contract when the net benefit of defaulting is smaller than the net benefit of paying back the debt. While the former is related to the size of the existing debt level, the latter involves a loss of access to the international credit market and possibly other disturbances. The two-period time horizon allows us, similar to Acharya & Rajan (2013), to take a shortcut for modeling such disturbances. Default in period 2 causes a utility loss of size z in that period, representing the discounted value from being unable to borrow in the future among other possible disadvantages. The period 2 utility in jurisdiction i is given by

$$u_{i2} = N_{i2} + \gamma g_{i2} - \kappa_i z.$$

We denote the government's default decision with the binary variable $\kappa_i = \{0, 1\}$, where 0 stands for no default and 1 for default. Two comments are in order. First, we do not model the default decision on government debt regarding initial (legacy) debt b_{i0} in period 1. Legacy debt levels may accumulate due to unforeseen shocks as in the recent European financial and economic crisis, or may play a role when switching to a more decentralized tax system (as is considered in the reform debate on fiscal federalism in Germany).[4] Second, we like to highlight that in our model the fixed interest rate and the binary government default decision are separated. Alternatively, one could assume that the interest rate on debt depends positively on the size of debt b_{i1} due to default risk. In that case the government would face an increasing marginal cost of borrowing. By contrast, in this extension of our model default prohibits any borrowing beyond a certain level. This approach has certain advantages in terms of tractability and captures explicitly that the rising cost of borrowing originate from the possibility of default. We discuss the assumption of a fixed interest rate in more detail in in Section 5.3.

Next, we analyze the default decision in period 2, holding tax rates in both jurisdictions constant for the moment. For this purpose, we need to compare the utilities under default and under no default, which defines a willingness-to-pay threshold b^{wtp} at which the

[4] Our assumption of repayment of legacy debt is reasonable if its size is small enough so that default in period 1 is not attractive. Even if a government default was attractive in period 1, it would not occur in equilibrium, since creditors would not have given any loans in the first place. We checked that there exists a set of sufficiently small initial debt levels that does not lead to default in period 1 but still influences the subsequent choice of fiscal instruments.

government is indifferent:

$$u_{i2}(\kappa_i = 1) = u_{i2}(\kappa_i = 0) \Leftrightarrow N_{i2} + \gamma N_{i2}\tau_{i2} - z = N_{i2} + \gamma\left(N_{i2}\tau_{i2} - b^{wtp}(1+r)\right)$$
$$\Leftrightarrow b^{wtp} = \frac{z}{\gamma(1+r)}.$$

If $b_{i1} > b^{wtp}$, a jurisdiction does not repay its debt as the benefits from default outweigh the related costs, and vice versa.[5]

The additive structure of the within period 2 utility allows us to separate the tax and default decisions. The government could choose a different tax rate in case of default than when honoring debt contracts. There is no incentive to do so, however, as tax rate choices are best responses that do not depend on default as long as the level of public good provision is strictly positive, that is, tax revenue exceeds the repayment burden resulting from debt in period 1. The latter holds as long as the willingness-to-pay threshold is sufficiently strict, which is fulfilled for a sufficiently small z.[6]

With endogenous default, the optimal default decision by the government in period 2 is
$$\tilde{\kappa}_i(b_{i1}) = \begin{cases} 0 & \text{if } b_{i1} \leq b^{wtp} \\ 1 & \text{if } b_{i1} > b^{wtp}. \end{cases}$$

The result shows that a government defaults when its debt level exceeds b^{wtp}. Therefore, no lender gives loans above this threshold. We thus have an upper limit on borrowing in the form of a borrowing constraint which is defined as follows.

Condition 1 (borrowing constraint)**.** $b_{i1} \leq b^{wtp} = \frac{z}{\gamma(1+r)}$.

The advantage of Condition 1 is its simplicity, as it does not depend on public investment and legacy debt levels. The upper limit b^{wtp} is the equivalent to $\bar{b}_i$.

C.2 Interaction Between Initial Public Infrastructure and Initial Public Debt

Unrestricted Borrowing Let $\bar{q}_i = \bar{q}_i(b_{i0})$, $i = 1, 2$. Condition (14) must be modified and reads

$$c'(m_i) = \frac{\beta\rho}{3}\left(1 + \frac{\rho}{3\nu}\Delta m_i + \frac{\rho}{3\nu}\Delta\bar{q}_i(1-\delta)\right), \; i = 1, 2. \tag{C.1}$$

Taking the total differential of (C.1) with respect to m_i and b_{i0}, we obtain

$$\frac{dm_i}{db_{i0}} = \frac{\frac{\beta\rho^2}{9\nu}(1-\delta)}{c''(m_i) - \frac{\beta\rho^2}{9\nu}}\bar{q}_i', \; i = 1, 2 \tag{C.2}$$

[5] b^{wtp} is identical across jurisdictions because they face the same z. This assumption simplifies the derivation but is not crucial for our results. In fact, heterogeneous utility losses in case of default are one of the reasons why the borrowing constraint that we derive below may be binding in one jurisdiction and not the other.

[6] When inserting b^{wtp} as the maximum debt level for b_{i1} into (5), it becomes obvious that $g^*_{i0} > 0 \Longleftrightarrow \frac{z}{\gamma} < \tau^*_{i2}N^*_{i2}$.

where $\bar{q}_i' = \frac{\partial \bar{q}_i'}{\partial b_{i0}}$. Again, we assume that the cost function is sufficiently convex, $c''(m_i) > \frac{\beta\gamma\rho^2}{9\nu}$, such that the second-order conditions are fulfilled. Then (C.2) implies

$$\frac{dm_i}{db_{i0}} \lesseqgtr 0 \Longleftrightarrow \bar{q}_i' \lesseqgtr 0. \tag{C.3}$$

Restricted Borrowing in Jurisdiction 1 The sign of (15) depends on $\frac{\partial^2 U^1}{\partial m_1 \partial b_{10}}$. Let $\bar{q}_1 = \bar{q}_1(b_{10})$ and differentiate (A.5) w.r.t. b_{10} to obtain

$$\begin{gathered}\frac{\partial^2 U^1}{\partial m_1 \partial b_{10}} = h_{11}'' \frac{\gamma^2}{\beta} c' + \left(\beta\left(1-\delta\right)\eta_{12} + \eta_{11}\right)\bar{q}_1', \\ \eta_{11} = -h_{11}''\gamma c' \frac{\partial(N_{11}(1+\gamma\tau_{11}))}{\partial \bar{q}_1} > 0,\ \eta_{12} = h_{12}''\left(\frac{\partial(N_{12}(1+\gamma\tau_{12}))}{\partial m_1}\right)^2 + h_{12}'\frac{\gamma\rho^2}{9\nu}.\end{gathered} \tag{C.4}$$

The first term in (C.4) captures the effect of b_{10} on the marginal utility of public infrastructure investment ($\frac{\partial U^1}{\partial m_1}$) that results from its impact on the incentives for inter-temporal redistribution as described in Proposition 3. The second term $\left(\beta\left(1-\delta\right)\eta_{12} + \eta_{11}\right)\bar{q}_1'$ represents the change in $\frac{\partial U^1}{\partial m_1}$ caused by a change in $\bar{q}_1 = \bar{q}_1(b_{10})$ that is due to the variation in the marginal utility of public infrastructure investment in period 1, η_{11}, and period 2, η_{12}. In order to obtain a reversal of the result in Proposition 3, such that a rise in jurisdiction i's legacy debt (b_{i0}) leads to an increase in i's infrastructure investment (m_i) and period 2 tax rate (τ_{i2}), the following assumption must hold.

Assumption 1. *An increase in initial public infrastructure $\bar{q}_i$ raises the marginal utility of public infrastructure investment in period 1. It does so at a rate greater in magnitude than the coinciding marginal change in the repayment burden.*

The first part of Assumption 1 ensures that a higher level of initial public infrastructure incentivizes governments to raise infrastructure investment in period 1. This holds if public investments are strategic substitutes. In the reverse case, any positive relation between initial infrastructure and initial debt would merely reinforce the effect described in Proposition 2 as an increase in b_{i0} would unambiguously reduce the marginal utility of public infrastructure investment in period 1. The second part of Assumption 1 states that the positive effect of $\bar{q}_i$ on the marginal utility of public infrastructure investment dominates the overall effect.

The effect of initial infrastructure investment depends on the sign of the second term in (C.4), $\left(\beta\left(1-\delta\right)\eta_{12} + \eta_{11}\right)\bar{q}_1'$. It is assumed to be positive (first part of Assumption 1). The assumption is satisfied in the quasi-linear case with $h_{12}'' = 0$, because then $\eta_{12} = h_{12}'\frac{\gamma\rho^2}{9\nu} > 0$. If $\left(\beta\left(1-\delta\right)\eta_{12} + \eta_{11}\right)\bar{q}_1' > 0$, and $\left|h_{11}''\frac{\gamma^2}{\beta}c'\right| < \left|\left(\beta\left(1-\delta\right)\eta_{12} + \eta_{11}\right)\bar{q}_1'\right|$, as stated in the second part of Assumption 1, we have

$$\frac{dm_1}{db_{10}} \lesseqgtr 0 \Longleftrightarrow \bar{q}_1' \lesseqgtr 0. \tag{C.5}$$

Under Assumption 1 the negative effect of an increase in initial public debt on infrastructure investment in period 1 is reinforced when there is a negative relationship between legacy debt and initial public infrastructure ($\bar{q}_1' < 0$).

C.3 General Utility Function

We assume the following nonlinear sub-utility function: $u_{it} = N_{it} + f_{it}(g_{it})$ with $f_{it}' > 0$ and $f_{it}'' \leq 0$. In order to derive the main results in this setting, we make several assumptions that preserve the strategic nature of the policy instruments in the fiscal competition game. These assumptions are summarized as follows.

Assumption 2. *A higher level of infrastructure investments induces a government to set higher tax rates,* $\frac{\partial^2 U^i}{\partial \tau_{it} \partial q_{it}} > 0$*. Taxes are strategic complements,* $\frac{\partial^2 U^i}{\partial \tau_{it} \partial \tau_{jt}} > 0$*. Public infrastructure investments are strategic substitutes* $\frac{\partial^2 U^i}{\partial m_{it} \partial m_{jt}} < 0$*.*

This assumption is consistent with our benchmark model and plausible against the backdrop of empirical findings (Hauptmeier *et al.*, 2012) and previous theoretical studies (Cai & Treisman, 2005; Hindriks *et al.*, 2008).

As in the benchmark analysis, we begin by solving the Nash equilibrium in period 2. The first-order condition for tax policy is given by

$$U^i_{\tau_{it}} := \frac{\partial U^i}{\partial \tau_{i2}} = \beta h_{i2}' \left(\frac{\partial N_{i2}}{\partial \tau_{i2}} + f_{i2}'(g_{i2}) \left(N_{i2} + \frac{\partial N_{i2}}{\partial \tau_{i2}} \tau_{i2} \right) \right) = 0, \; i = 1, 2. \tag{C.6}$$

The second-order condition holds because

$$\frac{\partial^2 U^i}{\partial \tau_{i2}^2} = \beta h_{i2}' \left(f''(g_{i2}) \left(N_{i2} + \frac{\partial N_{i2}}{\partial \tau_{i2}} \tau_{i2} \right)^2 + 2 f_{i2}'(g_{i2}) \frac{\partial N_{i2}}{\partial \tau_{i2}} \right) < 0 \tag{C.7}$$

where we have inserted the first-order condition. Condition (C.6) yields the reaction functions $t_{i2} = t_{i2}(\tau_{it}, q_{i,t-1}, q_{j,t-1}, b_{j,t-1}), \; i = 1, 2$ which can be solved to obtain the implicit best reply function of jurisdiction i:

$$Z_{i2} = \beta h_{i2}' \left(-\frac{1}{2\nu} + f_{i2}'(g_{i2}) \left(N_{i2} + \frac{1}{2\nu} \tau_{i2} \right) \right).$$

In the following, we denote the Nash equilibrium tax rates resulting from the fiscal competition game in period 2 by

$$\tilde{\tau}_{i2} = \tilde{\tau}_{i2}(q_{i2}, q_{j2}, b_{i1}), \; i = 1, 2, \tag{C.8}$$

$$\tilde{N}_{i2} = \tilde{N}_{i2}(q_{i2}, q_{j2}, b_{i1}), \; i = 1, 2. \tag{C.9}$$

In order to determine how $\tilde{\tau}_{i2}$ (and $\tilde{N}_{i2}$) adjusts in equilibrium to a change in q_i, q_j, b_i and b_j, we totally differentiate Z_{i2} with respect to $\tilde{\tau}_{i2}$ and the variable of interest and solve for the relevant differential. We obtain

$$\frac{d\tilde{\tau}_{i2}}{dq_{i2}} = -\frac{\frac{\partial Z_i}{\partial q_{i,2}}}{\frac{\partial Z_i}{\partial \tilde{\tau}_{i2}}}, \quad \frac{d\tilde{\tau}_{i2}}{dq_{j2}} = -\frac{\frac{\partial Z_i}{\partial q_{j,t-1}}}{\frac{\partial Z_i}{\partial \tilde{\tau}_{i2}}}, \quad \frac{d\tilde{\tau}_{i2}}{db_{i2}} = -\frac{\frac{\partial Z_i}{\partial b_{i2}}}{\frac{\partial Z_i}{\partial \tilde{\tau}_{i2}}}$$

where

$$\begin{aligned}
\frac{\partial Z_i}{\partial \tilde{\tau}_{i2}} =& \beta h'_{it}\left(f''_{i2}\tilde{N}_{i2}\left(\tilde{N}_{i2} - \frac{1}{2\nu}\tilde{\tau}_{i2}\right) - \frac{1}{2\nu}f'_{i2}\right) + \left(\frac{\partial t_{j2}}{\partial \tilde{\tau}_{i2}} - 1\right)\frac{\partial^2 U^i}{\partial \tau_{i2}\partial q_{i,2}}, \\
\frac{\partial Z_i}{\partial q_{i,2}} =& \rho\left(\frac{\partial t_{j2}}{\partial q_{i,2}} + \rho\right)\frac{\partial^2 U^i}{\partial \tau_{i2}\partial q_{i,2}}, \\
\frac{\partial Z_i}{\partial q_{j,t-1}} =& \rho\left(\frac{\partial t_{j2}}{\partial q_{j,2}} - \rho\right)\frac{\partial^2 U^i}{\partial \tau_{i2}\partial q_{i,2}}, \\
\frac{\partial Z_i}{\partial b_{i2}} =& h'_{i2}f''_{i2}\left(\tilde{N}_{i2} - \frac{1}{2\nu}\tilde{\tau}_{i2}\right).
\end{aligned}$$

Note that we have $\tilde{N}_{i2} - \frac{1}{2\nu}\tilde{\tau}_{i2} > 0$ under the first-order condition (C.6) and $\frac{\partial t_{j2}}{\partial q_{i,2}} + \rho > 0$, $\frac{\partial t_{j2}}{\partial q_{j,2}} - \rho < 0$ because

$$\begin{aligned}
\frac{dt_{i2}}{dm_j} + \rho \Longleftrightarrow & -\frac{\partial^2 U^i}{\partial \tau_{i2}\partial q_{i,2}} < \rho\frac{\partial^2 U^i}{\partial \tau_{i2}^2} \\
\Longleftrightarrow & \frac{1}{2\nu}f''_{j2}\left(N_{j2} + \frac{\partial N_{j2}}{\partial \tau_{j2}}\tau_{j2}\right)\tau_{jt2} < -f''_{j2}\left(N_{j2} + \frac{\partial N_{j2}}{\partial \tau_{j2}}\tau_{j2}\right)^2 + \frac{1}{2\nu}f'_{j2}, \\
\frac{\partial t_{j2}}{\partial q_{j,2}} - \rho \Longleftrightarrow & -\frac{\partial^2 U^j}{\partial \tau_{jt}\partial q_{j,t-1}} < \rho\frac{\partial^2 U^j}{\partial \tau_{jt}^2} \\
& -\frac{1}{2\nu}f''_{j2}\left(N_{j2} + \frac{\partial N_{j2}}{\partial \tau_{j2}}\tau_{j2}\right)\tau_{jt2} > f''_{j2}\left(N_{j2} + \frac{\partial N_{j2}}{\partial \tau_{j2}}\tau_{j2}\right)^2 - \frac{1}{2\nu}f'_{j2}.
\end{aligned}$$

It follows that $\frac{\partial Z_i}{\partial \tilde{\tau}_{i2}} < 0$, $\frac{\partial Z_i}{\partial q_{i,2}} > 0$, $\frac{\partial Z_i}{\partial q_{j,t-1}} < 0$ and $\frac{\partial Z_i}{\partial b_{i2}} < 0$ such that $\frac{d\tilde{\tau}_{i2}}{dq_{i2}} > 0$, $\frac{d\tilde{\tau}_{i2}}{dq_{j2}} < 0$ and $\frac{d\tilde{\tau}_{i2}}{db_{i2}} < 0$.

Case I: The Borrowing constraint is not binding in either of the two jurisdiction

After inserting budget constraints, both governments $i = 1, 2$ solve the following maximization problem

$$\begin{aligned}
\max_{\tau_{i1}, m_i, b_{i1}} U^i =& h_{i1}\left(N_{i1} + f_{i1}\left(\tau_{i1}N_{i1} - c - (1+r)\,b_{i0} + b_{i1}\right)\right) \\
&+ \beta h_{i2}\left(\tilde{N}_{i2} + f_{i2}\left(\tilde{\tau}_{i2}\tilde{N}_{i2} - (1+r)\,b_{i1}\right)\right) \text{ s.t. } g_{i1} \geq 0,\ m_i \geq 0.
\end{aligned} \tag{C.10}$$

The first-order conditions are given by

$$\frac{\partial U^i}{\partial \tau_{i1}} = h'_{i1}\left(\frac{\partial N_{i1}}{\partial \tau_{i1}} + f'_{i1}(g_{i1})\left(N_{i1} + \frac{\partial N_{i1}}{\partial \tau_{i1}}\tau_{i1}\right)\right) = 0, \quad \text{(C.11)}$$

$$\frac{\partial U^i}{\partial m_{i1}} = -h'_{i1} f'_{i1}(g_{i1})\, c' + \beta h'_{i2}\left(\frac{\partial \tilde{N}_{i2}}{\partial m_i} + f'_{i2}(g_{i2})\left(\frac{\partial \tilde{N}_{i2}}{\partial m_i}\tilde{\tau}_{i2} + \frac{\partial \tilde{\tau}_{i2}}{\partial m_i}\tilde{N}_{i2}\right)\right) = 0, \quad \text{(C.12)}$$

$$\frac{\partial U^i}{\partial b_{i1}} = h'_{i1} f'_{i1}(g_{i1}) + \beta h'_{i2}\left(\frac{\partial \tilde{N}_{i2}}{\partial b_{i1}} + f'_{i2}(g_{i2})\left(\frac{\partial \tilde{\tau}_{i2}}{\partial b_{i1}}\tilde{N}_{i2} + \frac{\partial \tilde{N}_{i2}}{\partial b_{i1}}\tilde{\tau}_{i2} - (1+r)\right)\right) = 0. \quad \text{(C.13)}$$

Substituting (C.13) into (C.12) yields

$$c' = -\frac{\frac{\partial \tilde{N}_{i2}}{\partial m_i} + f'_{i2}(g_{i2})\left(\frac{\partial \tilde{N}_{i2}}{\partial m_i}\tilde{\tau}_{i2} + \frac{\partial \tilde{\tau}_{i2}}{\partial m_i}\tilde{N}_{i2}\right)}{\frac{\partial \tilde{N}_{i2}}{\partial b_{i1}} + f'_{i2}(g_{i2})\left(\frac{\partial \tilde{\tau}_{i2}}{\partial b_{i1}}\tilde{N}_{i2} + \frac{\partial \tilde{N}_{i2}}{\partial b_{i1}}\tilde{\tau}_{i2} - (1+r)\right)}. \quad \text{(C.14)}$$

If $f'_{i2} = \gamma$, we obtain

$$c' = \beta\left(\gamma\frac{\partial \tilde{N}_{i2}}{\partial m_i} + \frac{\partial \tilde{N}_{i2}}{\partial m_i}\tilde{\tau}_{i2} + \frac{\partial \tilde{\tau}_{i2}}{\partial m_i}\tilde{N}_{i2}\right). \quad \text{(C.15)}$$

which is again independent of b_{i0} as stated in Proposition 2.

Case II: The Borrowing constraint is binding in one jurisdiction

Making use of the Dixit (1986) stability assumptions we obtain

$$\frac{\mathrm{d}m_1}{\mathrm{d}b_{10}} = -\frac{1}{\phi}\frac{\partial^2 U^2}{\partial m_2^2}\frac{\partial^2 U^1}{\partial m_1 \partial b_{10}} < 0, \quad \text{(C.16)}$$

$$\frac{\mathrm{d}m_2}{\mathrm{d}b_{10}} = \frac{1}{\phi}\frac{\partial^2 U^2}{\partial m_2 \partial m_1}\frac{\partial^2 U^1}{\partial m_1 \partial b_{10}} > 0. \quad \text{(C.17)}$$

Note that

$$\frac{\partial^2 U^1}{\partial m_1 \partial b_{10}} = h''_{i1}\left(f'_{i1}\right)^2 c'_i(1+r) + h'_{i1} f''_{i1} c'_i (1+r) < 0. \quad \text{(C.18)}$$

The inequality in expression (C.17) follows from Assumption 2. The effect of a change in b_{i0} on τ_{i2} is given by

$$\frac{\mathrm{d}\tilde{\tau}_{i2}}{\mathrm{d}b_{i0}} = \frac{\mathrm{d}\tilde{\tau}_{i2}}{\mathrm{d}m_i}\frac{\mathrm{d}m_i}{\mathrm{d}b_{i0}} + \frac{\mathrm{d}\tilde{\tau}_{i2}}{\mathrm{d}m_j}\frac{\mathrm{d}m_j}{\mathrm{d}b_{i0}} < 0,$$

$$\frac{\mathrm{d}\tilde{\tau}_{j2}}{\mathrm{d}b_{i0}} = \frac{\mathrm{d}\tilde{\tau}_{j2}}{\mathrm{d}m_j}\frac{\mathrm{d}m_j}{\mathrm{d}b_{i0}} + \frac{\mathrm{d}\tilde{\tau}_{j2}}{\mathrm{d}m_i}\frac{\mathrm{d}m_i}{\mathrm{d}b_{i0}} > 0$$

where we have made use of the results derived above with regard to $\frac{d\tilde{\tau}_{i2}}{dq_{i2}} = \frac{\mathrm{d}\tilde{\tau}_{i2}}{\mathrm{d}m_i}$ and $\frac{d\tilde{\tau}_{i2}}{dq_{j2}} = \frac{\mathrm{d}\tilde{\tau}_{i2}}{\mathrm{d}m_j}$.

C.4 A Tax on Domestic Income

We consider an additional tax on an immobile tax base. We assume that a fraction $0 \leq \omega \leq 1$ of the local benefit of firm investment N_{it} is taxed at τ_{i1}^w. One may think of ωN_{it} as a wage which is taxed with a labor tax. We also introduce a welfare loss from taxation by assuming that the corresponding tax revenue is reduced by administrative costs which are a convex function of τ_{i1}^w.[7] The budget constraints thus read

$$g_{i1} = \tau_{i1} N_{i1} + \left(\tau_{i1}^w - \xi \frac{\left(\tau_{i1}^w\right)^2}{2} \right) \omega N_{i1} - c(m_i) - (1+r)\, b_{i0} + b_{i1}, \tag{C.19}$$

$$g_{i2} = \tau_{i2} N_{i2} + \left(\tau_{i2}^w - \xi \frac{\left(\tau_{i2}^w\right)^2}{2} \right) \omega N_{i2} - (1+r)\, b_{i1}, \tag{C.20}$$

and governments maximize

$$\begin{aligned} U^i = h_{i1}\left(u_{i1}\right) + \beta h_{i2}(u_{i2}) =& h_{i1}\left(\left(1-\omega\right) N_{i1} + \left(1-\tau_{i1}^w\right) \omega N_{i1} + \gamma g_{i1}\right) \\ &+ \beta h_{i2}\left(\left(1-\omega\right) N_{i2} + \left(1-\tau_{i2}^w\right) \omega N_{i2} + \gamma g_{i2}\right). \end{aligned} \tag{C.21}$$

Solving by backward induction, the set of first-order conditions in period 2 - given by (8) - is extended by the optimal choice of τ_{i2}^w:

$$U^i_{\tau_{i2}^w} := \frac{\partial U^i}{\partial \tau_{i2}^w} = h_{i2}' \frac{\partial u_{i2}}{\partial \tau_{i2}^w} = 0. \tag{C.22}$$

The optimal labor tax equals $\tau_{i2}^{w*} = \frac{\gamma-1}{\gamma\xi}$. Substituting into (8), we can determine capital tax rates and the number of firms in a similar way as stated in Proposition 1:

$$\tilde{\tau}_{i2}\left(m_i, m_{-i}\right) = \nu - \frac{1}{\gamma} + \frac{\rho \Delta q_i}{3} - \frac{\left(\gamma-1\right)^2}{2\gamma^2\xi}\omega, \tag{C.23}$$

$$\tilde{N}_{i2}\left(m_i, m_{-i}\right) = \frac{1}{2} + \frac{\rho \Delta q_i}{6\nu}, \tag{C.24}$$

$$\tau_{i2}^{w*} = \frac{\gamma - 1}{\gamma\xi}, \tag{C.25}$$

$$\tilde{\kappa}_i\left(b_{i1}\right) = \begin{cases} 0 & \text{if } b_{i1} \leq b^{wtp} \\ 1 & \text{if } b_{i1} > b^{wtp}, \end{cases} \tag{C.26}$$

$$\tilde{g}_{i2}\left(m_i, m_{-i}, b_{i1}\right) = \tilde{\tau}_{i2} \tilde{N}_{i2} - (1 - \tilde{\kappa}_i)(1+r) b_{i1}. \tag{C.27}$$

[7] Ignoring administrative costs yields an equilibrium where $\tau_{i1}^w = 1$ since $\gamma > 1$ and the results of the main analysis are immediately obtained.

Solving period 2, we begin with the case where the borrowing constraint is not binding in both jurisdictions. The maximization problem of jurisdiction i is given by

$$\max_{\tau_{i1},m_i,b_{i1},\tau^w_{i1}} U^i = h_{i1}\left(\left(1-\omega\right)N_{i1} + \left(1-\tau^w_{i1}\right)\omega N_{i1} + \gamma g_{i1}\right) + \beta h_{i2}\left(\left(1-\omega\right)\tilde{N}_{i2} + \left(1-\tau^{w*}_{i2}\right)\omega \tilde{N}_{i2} + \gamma \tilde{g}_{i2}\right), \tag{C.28}$$

which leads to the first-order conditions

$$\frac{\partial U^i}{\partial \tau_{i1}} = h'_{i1}\frac{\partial u_{i1}}{\partial \tau_{i1}} = 0, \tag{C.29}$$

$$\frac{\partial U^i}{\partial m_{i1}} = -h'_{i1}\gamma c' + \beta h'_{i2}\frac{\partial \tilde{u}_{i2}}{\partial m_i} = 0, \tag{C.30}$$

$$\frac{\partial U^i}{\partial b_{i1}} = \gamma h'_{i1} - \beta\gamma(1+r)h'_{i2} = h'_{i1} - h'_{i2} = 0, \tag{C.31}$$

$$\frac{\partial U^i}{\partial \tau^w_{i1}} = h'_{i2}\frac{\partial u_{i1}}{\partial \tau^w_{i1}} = 0. \tag{C.32}$$

The Hessian for the system of first-order conditions (C.29) to (C.32) for jurisdiction i is given by

$$\boldsymbol{H} = \begin{pmatrix} \frac{\partial^2 U^i}{\partial m_i^2} & \frac{\partial^2 U^i}{\partial \tau_{i1}\partial m_i} & \frac{\partial^2 U^i}{\partial b_{i1}\partial m_i} & \frac{\partial^2 U^i}{\partial \tau^w_{i1}\partial m_i} \\ \frac{\partial^2 U^i}{\partial m_i\partial \tau_{i1}} & \frac{\partial^2 U^i}{\partial \tau_{i1}^2} & \frac{\partial^2 U^i}{\partial b_{i1}\partial \tau_i} & \frac{\partial^2 U^i}{\partial \tau^w_{i1}\partial \tau_i} \\ \frac{\partial^2 U^i}{\partial m_i\partial b_{i1}} & \frac{\partial^2 U^i}{\partial \tau_{i1}\partial b_{i1}} & \frac{\partial^2 U^i}{\partial b_{i1}^2} & \frac{\partial^2 U^i}{\partial \tau^w_{i1}\partial b_{i1}} \\ \frac{\partial^2 U^i}{\partial m_i\partial \tau^w_{i1}} & \frac{\partial^2 U^i}{\partial \tau_{i1}\partial \tau^w_{i1}} & \frac{\partial^2 U^i}{\partial \tau^w_{i1}} & \frac{\partial^2 U^i}{\partial \left(\tau^w_{i1}\right)^2} \end{pmatrix} = \begin{pmatrix} \frac{\partial^2 U^i}{\partial m_i^2} & 0 & \frac{\partial^2 U^i}{\partial b_{i1}\partial m_i} & 0 \\ 0 & \frac{\partial^2 U^i}{\partial \tau_{i1}^2} & 0 & 0 \\ \frac{\partial^2 U^i}{\partial m_i\partial b_{i1}} & 0 & \frac{\partial^2 U^i}{\partial b_{i1}^2} & 0 \\ 0 & 0 & 0 & \frac{\partial^2 U^i}{\partial \left(\tau^w_{i1}\right)^2} \end{pmatrix}$$

In the second term, we insert the first-order condition for taxes (C.29) to verify that $\frac{\partial^2 U^i}{\partial m_i\partial \tau_i} = -h''_{i1}\frac{\partial(N_{i1}(1+\gamma\tau_{i1}))}{\partial \tau_{i1}}\gamma c' = 0$ and $\frac{\partial^2 U^i}{\partial b_{i1}\partial \tau_i} = \gamma h''_{i1}\frac{\partial(N_{i1}(1+\gamma\tau_{i1}))}{\partial \tau_{i1}} = 0$. For (C.29)-(C.32) to yield a maximum, $\boldsymbol{H}$ must be negative definite which is the case if and only if

$$\frac{\partial^2 U^i}{\partial m_i^2} < 0, \tag{C.33}$$

$$\frac{\partial^2 U^i}{\partial m_i^2}\frac{\partial^2 U^i}{\partial \tau_{i1}^2} > 0, \tag{C.34}$$

$$\frac{\partial^2 U^i}{\partial \tau_{i1}^2}\left(\frac{\partial^2 U^i}{\partial m_i^2}\frac{\partial^2 U^i}{\partial b_{i1}^2} - \left(\frac{\partial^2 U^i}{\partial b_{i1}\partial m_i}\right)^2\right) < 0. \tag{C.35}$$

$$\frac{\partial^2 U^i}{\partial \tau_{i1}^2}\frac{\partial^2 U^i}{\partial \left(\tau^w_{i1}\right)^2}\left(\frac{\partial^2 U^i}{\partial m_i^2}\frac{\partial^2 U^i}{\partial b_{i1}^2} - \left(\frac{\partial^2 U^i}{\partial b_{i1}\partial m_i}\right)^2\right) > 0. \tag{C.36}$$

Conditions (C.33), (C.34), and (C.35) are identical to the benchmark model (see Section A.1). Condition (C.36) holds whenever (C.35) holds because $\frac{\partial^2 U^i}{\partial \tau_{i1}^2} < 0$ and $\frac{\partial^2 U^i}{\partial (\tau_{i1}^w)^2} = -\gamma\xi < 0$.

The system of first-order conditions (C.29)-(C.32) can be solved to obtain equilibrium tax rates and the number of investments in period 1:

$$\tau_{i1}^* = \nu - \frac{1}{\gamma} - \frac{(\gamma-1)^2}{2\gamma^2\xi}\phi, \; \tau_{i1}^{w*} = \frac{\gamma-1}{\gamma\xi}, \; N_{i1}^* = \frac{1}{2}. \tag{C.37}$$

Noting that $\frac{\partial \tilde{u}_{i2}}{\partial m_i} = \frac{\gamma\rho}{3}\left(1 + \frac{\rho\Delta m_i}{3\nu}\right)$, we can substitute (C.31) into (C.30) to obtain the modified first-order condition for infrastructure investment $c'(m_i) = \frac{\beta\rho}{3}\left(1 + \frac{\rho\Delta m_i}{3\nu}\right)$ which is identical to (14) such that the results stated in Proposition 2 prevail.

Turning to the case where borrowing is constrained in jurisdiction 2, we note that the comparative static analysis is unaffected by the introduction of the additional tax instrument because $\frac{\partial \tilde{u}_{i2}}{\partial m_i}$ is independent of the choice of τ_{i1}^w. As a consequence, the results stated in Proposition 3 are also valid with a tax on the immobile tax base.

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