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Optimal Versus Actual Maturity of Government Debt: The Case of Greece

Basil Dalamagas[a], Stefanos Tantos[b]

[a] *Emeritus Professor in Public Finance, National & Kapodistrian University of Athens Department of Economics. Email: dalamaga@econ.uoa.gr*
[b] *Adjunct Lecturer in Public Finance, National & Kapodistrian University of Athens Department of Economics. Email: stantos@econ.uoa.gr*

Abstract

The purpose of the present paper is to examine theoretically and empirically how the maturity structure of government debt is affected by changes in its main macroeconomic determining factors. We organize our investigation around a maturity-structure model for Greece in which the optimal (annual) average maturity of a total of outstanding government bonds of different maturities is estimated over a thirty-year period. The optimal maturity level is then compared with the corresponding observed or actual level. We then use our empirical estimates to determine the response of optimal maturity to changes in its main determinants and make suggestions for corrective fiscal policy actions.

Keywords: public debt, Greece, maturity, deficit, growth rate, interest rate
JEL codes: H63, H62, E6, E62

1. Introduction

Research on debt management has revealed a weak systematic relation between the level of debt and its maturity. For example, Calvo and Guidotti (1992) argue that the United States have exhibited a positive relation between debt and maturity, with both maturity and the debt/GDP ratio decreasing until the mid 1970’s and increasing since then. On the other hand, Missale and Blanchard (1994) contend that in countries, with debt/GDP ratios approaching or exceeding 100 percent, the increase in debt has been associated with a sharp reduction in maturity, while, for most OECD countries over the period 1965-1995, a weak relationship between debt and maturity has been traced out. A detailed review of the evidence for OECD countries is given by Missale (1992).

However, a general framework to evaluate alternative fiscal and macroeconomic strategies on the design and implementation of an optimal maturity structure – as a prominent feature of debt management – has not yet emerged. A number of studies focus on optimal taxation as the most promising approach to the choice of debt instruments, with a purpose towards minimizing the welfare loss from distortionary taxation.

The optimal determination of the maturity structure of debt is also studied in the context of a financial-monetary equilibrium approach. Greenwood et al (2012) argue that holders of the riskless treasury bills derive monetary services in the form of a convenience premium (money-like claims, such as liquidity and security of nominal return). The monetary premium associated with short-term debt – i.e. the lower financing cost – is traded off by the government against the refinancing risk implied by the need to roll over its debt more often at unpredictable tax rates (more volatile future taxes).

Unlike the traditional tax-smoothing models which favour a long-term government debt[1], the above trade off setting predicts a positive correlation between debt maturity and the debt/GDP ratio, because the costs associated with roll over risk - and hence with failing to smooth taxes – increase significantly as the government debt grows.

Nosbusch (2008) argues that an exclusive focus on cost minimization may be misleading because interest costs may be associated with other desirable characteristics. In the proposed setup (uncertainty, distortionary taxation, risk aversion, market incompleteness), his policy prescription for the government to achieve optimal tax smoothing is to borrow long and invest short[2].

In general, there is a long literature on optimal public debt policy. To mention some of the relevant approaches, Guibaud et al (2008) propose a clientele-based theory of the optimal structure of government debt. Alfaro et al (2009) find that, given fundamentals, it may not be possible to lengthen the maturity structure and that, even when long maturity debt is sustainable, it may be associated with equilibria in which welfare levels are low. Jeanne (2009) contends that the welfare of countries, which have to roll-over large amounts of short-term external debt, could be improved by an international judicial mechanism allowing a suspension of their debt-servicing payments. Greenwood and Vayanos (2013) examine how the maturity structure of government debt affects bond yields and expected returns.

Despite the large amount of research devoted to studying the optimal maturity structure of government debt, there is yet no clear answer to the question of which macroeconomic factors actually determine such an optimal structure in the real world.

A number of contributions go beyond a general theoretical treatment by providing numerical solutions to various problems or by using empirical estimates to calibrate the models: For example, they solve simple calibrated versions of a theoretical model or they even calibrate artificial economies or they run baseline (*ad hoc*) regressions, involving the maturity as the dependent variable and the debt-GDP ratio (interest rates, inflation and so on) as the independent variable, along with some control variables.

The success of the above tax-smoothing or financial models in explaining much of the variation of the maturity structure of the public debt appears to be ambiguous. Inflation, interest rates, debt/GDP ratio and other variables are usually treated as exogenous, while the influence of the key macroeconomic and fiscal determinants on them and, thereby, on the maturity structure is ignored. It is difficult to obtain reliable

[1] The tax-smoothing motive for long-term finance has been put forward by Barro (1979), Lucas and Stokey (1983) and Bohn (1990), whereas Blanchard and Missale (1994) and Missale (1999) empirically examine how and why government debt maturity structure varies over time and across countries.

[2] For a cost-minimizing analysis, in the context of the financial structure of the government debt, see also De Broeck (1997) and Lucas and Stokey (1983).

results regarding the optimal maturity structure once we depart from a well-founded econometric modeling approach based on the fundamentals of an economy.

The present article extends the existing literature by incorporating the key macroeconomic and fiscal variables in a three-equation system that describes the evolution of the Greek government debt over the period 1980-2009. The optimal maturity structure is then determined on the basis of a relationship derived from solving a sovereign-debt minimization procedure. Thus, we manage to derive an explicit formula for the optimal debt composition and to provide a framework in which the optimal maturity structure can be evaluated against the actual maturity. The same process allows us to examine the effects of the macroeconomic factors on the maturity structure and explain the reasons underlying the diversion of optimal from actual maturity over time. We could address the question of optimal maturity using a sample of EU member countries with high or low debt/GDP ratios to explore whether the theory of optimal maturity structure would hold for them, given that they do not exhibit the extreme macroeconomic conditions of Greece. In such a case, we could examine the two types of factors at play, that is issuer characteristics and aggregate characteristics. Focusing on the macroeconomic characteristics, for one issuer only, implies that the difference between the two types of characteristics cannot be identified from the cross-section of issuers.

However, it would be advisable to focus on Greece, because the empirical model to be estimated should be separate for each country, given that it involves estimates on each country's specific growth rate, interest rates, real maturity structure etc. Since debt to GDP ratio does not influence the optimal maturity formula – as it is shown below – adding more countries to the list leads basically to running more systems of equations.

The article proceeds as follows. Section 2 presents the main features of the sovereign debt of Greece and summarizes the findings of the prior empirical work on the relationship between optimal maturity and other macro-variables. Section 3 presents the model. Section 4 organizes the empirical investigation of the determinants of optimal maturity and section 5 concludes.

2. The scope of the study

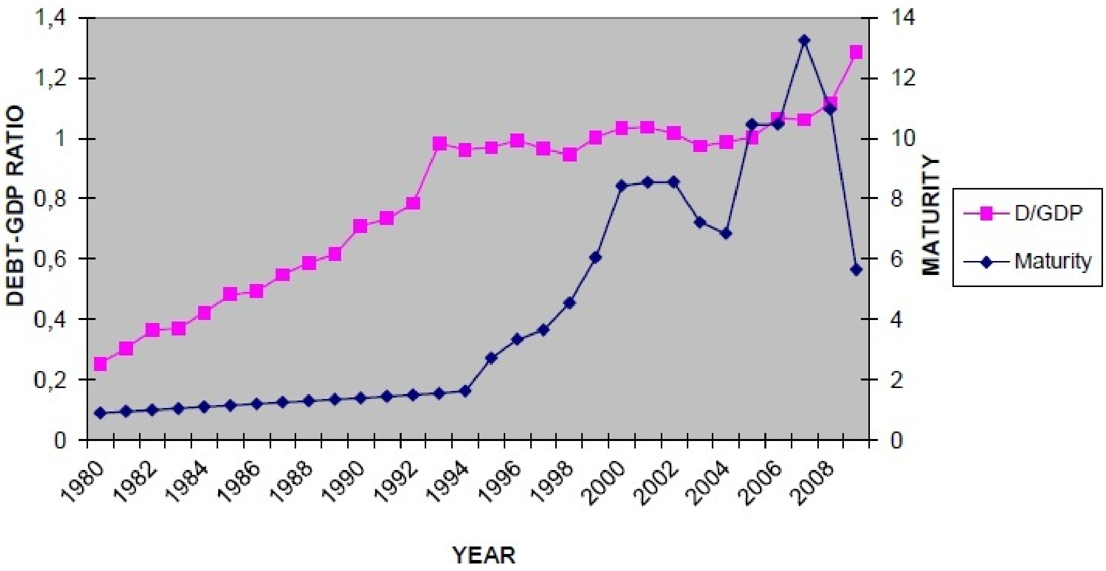
In the present paper, we propose a theory of optimal maturity structure that emphasizes the role of the key fiscal and macroeconomic variables in highly indebted countries, thus abstracting from the prevailing strands of research (tax smoothing, asset-pricing models, money-like convenience services, crowding out, preferred habitat models and so on). We show that, consistent with practical intuition but in contrast to most debt-management models, building the maturity structure in indebted countries is not associated solely with the aim of debt maturity policies to determine a welfare-maximizing debt portfolio or to minimize expected interest costs. As governments inherit a substantial stock of outstanding debt from their predecessors, abiding by any universally accepted fiscal rules is not considered to be the main goal of debt management. Motivated by practical concerns for growing public indebtedness, governments' attention falls on discovering and exploiting any available sources of financing to meet their payment obligations at any rate, in a desperate attempt to avoid default. In such a fiscal environment, it is the key macroeconomic and fiscal indicators as interpreted by the world financial markets that dictate the content of the maturity-structure policies.

Greece is the most striking recent paradigm of a country faced with a large amount of sovereign (foreign) debt, high budget and external deficits, low productivity, inefficient public administration and serious structural problems. The government has no access to world financial markets for funding its deficits and it escaped default because a massive support program of as high as €240 billion was initiated, being financed by the euro-zone countries, the European Central Bank and the International Monetary Fund (Troika) in 2010. These economic developments, the origins of which date back to the 1980's, render the adoption of any well-established theoretical criterion (tax smoothing, welfare maximization, crowding out etc.) at least tentative.

A thirty-year fiscal policy, focusing on the need to meet the ever increasing borrowing requirements of Greece from external sources, stands in stark contrast to the assumptions made by most of the theoretical and empirical literature on debt management. It would thus be advisable to shed light on the main features and the evolution of the public debt, as well as to examine its main determinants through time.

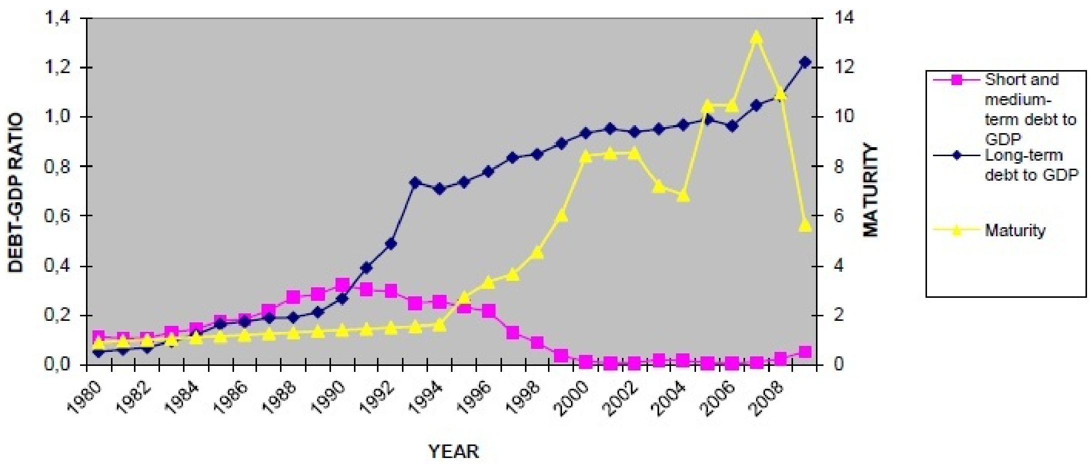
Figures 1 and 2 give the evolution of government debt (total, long-term, short and medium-term) and maturity (average, weighted) since 1980 for Greece (sources for the series and details of construction are given in the Appendix).

Figure 1. Total debt-GDP ratio and maturity, Greece



Sources: Eurostat for debt-GDP ratio and Ministry of Finance of Greece for actual maturity.

Figure 2. (Long-term and short and medium-term) debt-GDP ratio and maturity, Greece



Sources: Eurostat for short and medium-term and long-term debt-GDP ratio and Ministry of Finance of Greece for actual maturity.

Note: Short and medium-term debt includes treasury bills and bonds of maturity up to five years. Long-term debt refers to government bonds with maturity greater than five years.

The figures show that the sharp increase in the debt-GDP ratio (total and long-term), which started in the 1990's, has been accompanied by an even more pronounced increase in maturity. Note that:

i) The positive relation between long-term debt and maturity is even more striking than the corresponding one of the total debt.
ii) The maturity of debt has increased by as much as ten times between the years 1990 and 2007, it stood at 13.2 in 2007 but it fell to 5.7 two years later. The underlying reason for the drop in maturity in 2009 is that Greece would have liked to refinance all of its public debt using the longest maturity possible, but it could not do so because the costs of borrowing in say 10 year bonds would be extremely high. This is actually a pattern of term spreads (long-short rates) that one would typically encounter in countries near default episodes.

iii) The sample period does not extend beyond the year 2009; this is so because the design and implementation of economic policy in Greece from 2010 onwards is strictly surveilled by the Troika.

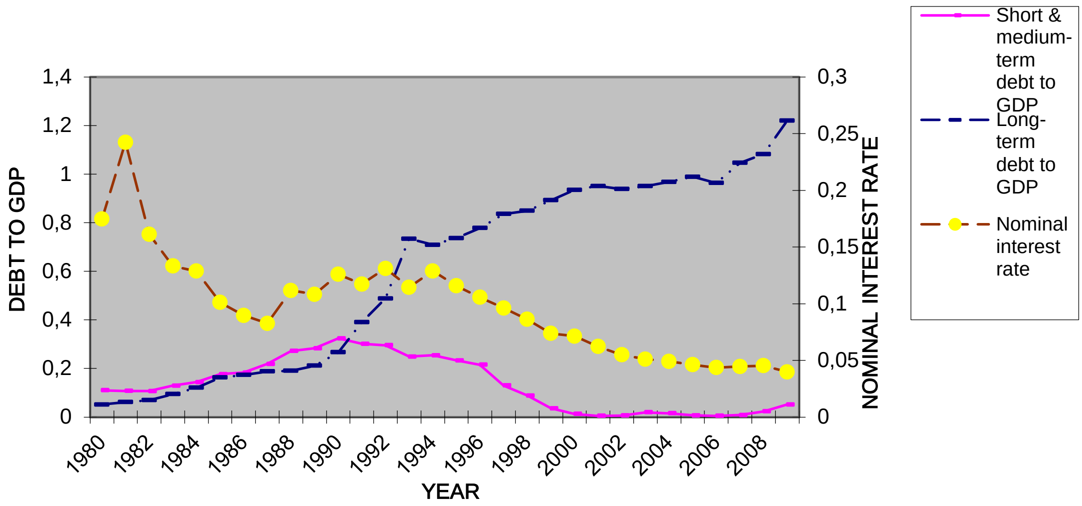
According to the standard convention on optimal maturity theory[3], the maturity of conventional securities (as well as their denomination) can partly compensate for the absence of explicitly contingent debt. The nominal debt, as it is mainly the Greek government debt, plays an important hedging role, because it is implicitly contingent on real shocks affecting the price level and, in addition, it allows policymakers to raise state-contingent inflation taxes. Greece actually used inflation taxes to distribute

[3] See, for example, Missale (1997).

the cost of the adjustment to public spending shocks over the sub-period 1980-2001. However, this is no more possible after joining the Eurozone in 2002.

Choosing the appropriate debt maturity – i.e. the maturity of the long-term debt – is often considered to be a substitute for contingent debt. Figure 3 reveals a clear tendency of the actual maturity structure in Greece (given by the curve of the long-term debt/GDP ratio) to lengthen through time, even though the nominal interest rate falls. However, a relation between longer maturity and lower financing cost does not fit into the framework of conventional economic theory.

Figure 3. (Long-term and short and medium-term) debt-GDP ratio and nominal interest rate, Greece



Sources: Eurostat for short and medium-term and long-term debt-GDP ratio and OECD for money supply

Normally, a long maturity structure is optimal if increases in public spending induce a positive correlation between real interest rates and government financing needs. The interest rates fall when (long-term) debt/GDP ratio increases in Figure 3 – contrary to the optimal maturity rule[4] – because the accession of Greece to the euro-zone offered the possibility to entering into long-term contracts at low interest rates which applied to the other euro-members as well. Accordingly, the Greek government was maybe able to access long-term funding paying low fixed interest payments each year for a long time period. Thus, the negative correlation between the interest rate and debt maturity may not be so puzzling after all.

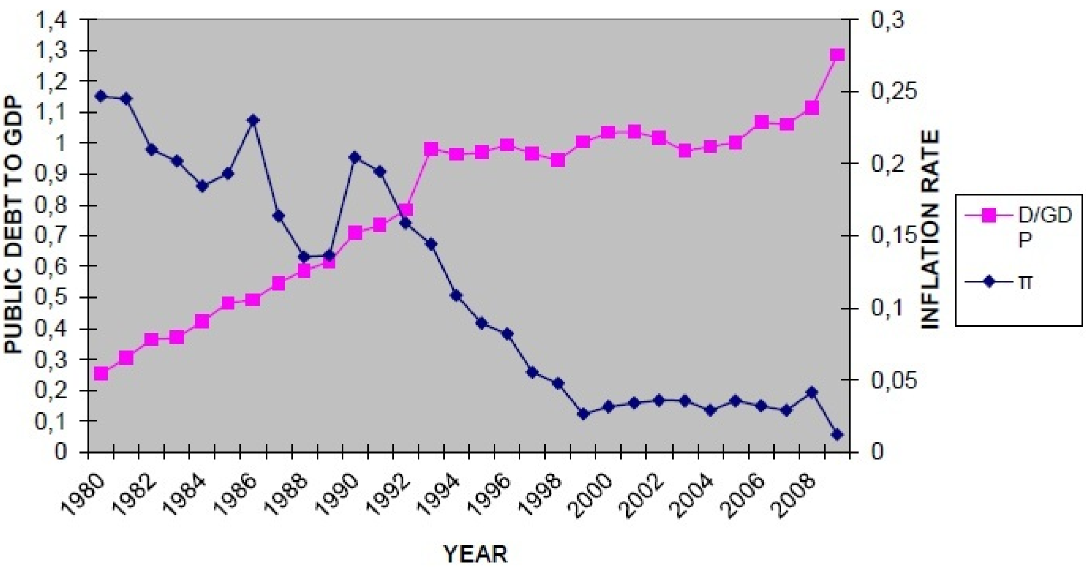
In summary, Greece faced steep yield curves in the 80s and the early 90s. It was only after the explicit commitment to join the common currency that the risk of

[4] It is understood that the argument laid down here is the tax smoothing theory of debt management. But one should not be convinced that the claim of a positive relationship between real interest rates and deficits is wrong because of the trends involved. For example, long-term nominal rates have dropped substantially in the sample because Greek governments could credibly commit to low inflation (i.e. the euro effect), at the same time debt to GDP and spending to GDP rose substantially. This does not mean that real rates have fallen and, even if they did, the unconditional correlation is not a convincing argument. One needs to look at fiscal shocks to government deficits and their effects on the term structure of interest rates in a VAR which identifies the shocks correctly to make the argument convincing.

inflation was mitigated (see fig. 4) and long bond yields decreased. Before joining the euro, the average maturity was low because of the high costs of financing long.

Another argument for long maturity debt holds (fails to hold) when expectations are for a sustained increase (decrease) in the price level. As inflation reduces the real value of the nominal debt, the effect of the higher price level on the debt value is increasing in debt duration, and vice versa. As shown in Figure 4, this does not seem to be the case with Greece, as decreasing rates of inflation are associated with increasing debt-GDP ratios.

Figure 4. Debt-GDP ratio and inflation rate, Greece



Sources: Eurostat for public debt-GDP ratio and OECD for inflation rate

From this point of view, the maturity structure of the Greek public debt appears to be suboptimal. In spite that the Greek economy was hit by strong public spending shocks (mainly of a consumption-type), these shocks did not lead to serially correlated inflation, so that the long maturity of nominal debt could not provide a better hedge than a short maturity for the purpose of tax smoothing.

No doubt, the exact characterization of optimal maturity is far from straightforward, since it depends on a number of factors affecting the budget. Whether lengthening the maturity is desirable or not depends on the stochastic relations between inflation, growth rate, real interest rate, primary balances, monetary disturbances and a lot of other variables entering (directly or indirectly) the government budget.

Figures 3 and 4 show that excessively high and increasing levels of long-term debt are associated with decreasing inflation and interest rates. Specifically,

i) The correlation between inflation and the debt-GDP ratio is negative and significant (-0.91). Even though a positive inflation-debt relationship would be justified on purely theoretical grounds, the above negative correlation suggests that there may exist an important role for long-term debt in hedging against frequent revisions in monetary policy or against frequent changes in tax rates, provided that the government is really concerned with limiting unnecessary variation in taxation and the price level.

ii) There appears to exist a negative correlation (-0.63) between the long-term debt-GDP ratio and the interest rate, measured as the ratio of annual interest payments to the outstanding public debt at the end of each year over the sample period (similar results are obtained when employing the real, long-term interest rate). This finding runs counter to the conventional wisdom, according to which lengthening the maturity structure is typically accompanied by an increase in the slope of the real yield curve, especially when shocks to public spending raise questions as to whether the government will be able to meet its debt-servicing obligations.

As noted above, the answer to the question of why world financial markets went on funding the increasing borrowing requirements of a highly indebted country at low interest rates has rather to do with the establishment of the Eurozone.

In the years prior to the accession of Greece to the euro area, i.e. up to 2002, fiscal authorities had to cope with the problem of conforming to the four basic criteria for membership (low interest rates, inflation rate up to 2%, budget deficit up to 3% of GDP and public debt-GDP ratio converging to the EU average of 60%). These criteria were gradually met, so that there was no reason for foreign investors to worry about the future prospects of the Greek economy. However, things changed after the adoption of ECU. The high cost of financing the Olympic Games in 2004 signaled the beginning of a process of continuous deviations from sound fiscal and incomes policies. Deregulation of the domestic monetary-credit system led to a re-direction of loans from productive to consumer uses at low interest rates; pressures from special interest groups (mainly labor unions), coupled with inadequate (almost corrupted) political leadership, led to a plethora of debt-financed, social-like provisions, far beyond the productive capacity of the country; on top of them, domestic "creative accounting" methods and a loose surveillance by the Eurozone authorities helped obscuring the real-economy developments.

With deliberate data shortages on crucial fiscal and macroeconomic indicators for Greece and with confidence to the reliability of the Eurozone institutional framework, objections that one might raise to an unfavorable economic performance carried little weight. Thus, it came without surprise that the widespread tendency among foreign private investors was to think of the Greek debt as free of any repudiation risk. On the other hand, the steep decline in long rates before and after joining the Eurozone induced the Treasury to tilt debt issuance towards long maturities. It was the world financial crisis of 2008 and the resulting liquidity constraints that forced the private creditors abroad to scrutinize the prevailing economic conditions in Greece and to discover that the restructure of the public debt was unavoidable. Thus, a multi-national solvency operation was urgently required to design and impose direct, strict stabilization measures. The steep rise in borrowing rates during 2009 proved to be the catalyst that forced the government to ask for a financial aid package from the Troika.

3. The Model

Unlike the theoretical and empirical investigations, mentioned above, this study introduces a novel way to identify optimal debt maturity. It is based on a simple present value model that is a modified version (for the public sector) of the model of Nam and Radulescu (2010). In the case of financing a given amount of public expenditure – in excess of tax revenue – through a loan or a debt issue equal to D, the government pays the creditor not only the annual interest of rD for s years, but also the entire amount of $D(=D_0)$ at the end of the borrowing period. Thus, the present value of debt at the base year, D_0*, can be expressed as follows:

$$D_0^* = D_0 e^{-rs} + \int_0^s rD_0 e^{-rt} dt \tag{1}$$

or, equivalently, after solving for the integral:

$$D_0^* = D_0 e^{-rs} + rD_0 \int_0^s e^{-rt} dt = D_0 e^{-rs} + rD_0 \frac{1}{r}(1-e^{-rs}) = D_0 e^{-rs} + D_0(1-e^{-rs}) = D_0 \tag{2}$$

where r is the real interest rate (0<r<1) and s represents the debt maturity years (s>0).

An important difference to be made when working on the maturity structure of debt, s, is that between the average maturity of the outstanding debt and the maturity of new debt issues. The present model is solved on the assumption that the entire maturity structure of the outstanding public debt is chosen at the end of each year. This assumption may not hold if a government inherits each period from a large stock of debt outstanding, while new debt issues represent a small fraction of the actual debt. In this case, the government may not achieve its desired average target in a dynamic setup.

However, any theoretical model that aims at performing an empirical exercise has to make simplifying assumptions. At the same time, one must take into account that, comparing the predicted maturity structure with the actual one does not possibly make full sense in a setup where the optimal maturity structure cannot be chosen optimally.

According to Nam and Radulescu (2010), in equilibrium, inflation does not play any role in financial decision making, provided that annual interest payments are estimated on the basis of the nominal interest rate for s years long:

$$D_{n,0}^* = D_0 e^{-(r+\pi)s} + \int_0^s (r+\pi) D_0 e^{-(r+\pi)t} dt = D_0 e^{-(r+\pi)s} + D_0(1-e^{-(r+\pi)s}) = D_0 \tag{3}$$

where $D_{n,0}^*$ is the nominal present value of debt at the base year and π is the inflation rate, 0<π<1.

However, if the interest payment takes place annually, applying the initial real interest rate, despite prevailing inflation, as it is the case in practice, then

$$\begin{aligned} D_{n,0}^* &= D_0 e^{-(r+\pi)s} + \int_0^s rD_0 e^{-(r+\pi)t} dt = D_0 e^{-(r+\pi)s} + \frac{rD_0}{r+\pi}(1-e^{-(r+\pi)s}) = \\ &= \frac{rD_0}{r+\pi} + D_0 e^{-(r+\pi)s}(1-\frac{r}{r+\pi}) = \frac{D_0}{r+\pi}[r+\pi e^{-(r+\pi)s}] < D_0 \end{aligned} \tag{4}$$

Starting with an initial balanced budget, let us now assume that new debt creation (budget deficit) is used to finance a government investment project of equal amount, B. We further postulate that the debt-financed investment project generates an infinite stream of future gross return A_0 which exponentially declines at the rate α (0<α<0.1).

Such a project is on the margin of acceptance when

$$\int_0^\infty A_0 e^{-(a+r+\pi)t}dt = B_0 e^{-(r+\pi)s} + \int_0^s (r+\pi+\kappa)B_0 e^{-(r+\pi+\kappa)t}dt \tag{5}$$

where κ stands for the remaining elements – besides interest payments – of the cost of debt issuance (for example the debt auction commission) which, for simplicity, are taken to be proportionally distributed across the maturity years.

In deriving eq. (5), we seem to impose that the Net Present Value (NPV) of the project is equal to zero. If indeed the NPV is zero then s is pinned down uniquely. Thus, such an assumption would not make sense. In addition, the general reason why we take first order conditions is to maximize the present value of profits, so that profits would be better to take on positive values.

Since fiscal variables are usually written as ratios to GDP, Eq. (5) may take the following form, under the assumption of an exponentially growing income, Y, at rate g ($-1<g<1$):

$$\int_0^\infty \frac{A_0 e^{-(a+r+\pi)t}}{Y_0 e^{gt}}dt - \frac{B_0 e^{-(r+\pi)s}}{Y_0 e^{gs}} - \int_0^s \frac{(r+\pi+\kappa)B_0 e^{-(r+\pi+\kappa)t}}{Y_0 e^{gt}}dt > 0 \tag{6}$$

The first term of Eq. (6) stands for the benefit to be derived from debt-financed public investment expenditure, whereas the sum of the second term (amortization payments) and the third term (interest payments and commission) represents the cost of the investment project. As a consequence, the difference between the benefit and the cost of debt creation may be viewed as the net present value, NPV, of the government intervention. After solving Eq. (6) and rearranging terms, we obtain

$$NPV = \int_0^\infty \frac{A_0}{Y_0} e^{-(a+r+\pi+g)t}dt - \frac{B_0}{Y_0} e^{-(r+\pi+g)s} - \int_0^s \frac{B_0}{Y_0}(r+\pi+\kappa)e^{-(r+\pi+g+\kappa)t}dt \tag{7}$$

The solution of (7) gives

$$NPV = \frac{A_0}{Y_0}\frac{1}{a+r+\pi+g} - \frac{B_0}{Y_0}e^{-(r+\pi+g)s} - \frac{B_0}{Y_0}\frac{r+\pi+\kappa}{r+\pi+g+\kappa}[1-e^{-(r+\pi+g+\kappa)s}] \tag{8}$$

Under the assumption of $0<\pi, r<1$, an optimal debt maturity, s*, is derived, if the first-order condition of Eq. (8) is set equal to zero

$$\frac{dNPV}{ds} = -\frac{B_0}{Y_0}[-(r+\pi+g)e^{-(r+\pi+g)s}] + \frac{B_0}{Y_0}\frac{(r+\pi+\kappa)}{(r+\pi+g+\kappa)}[-(r+\pi+g+\kappa)e^{-(r+\pi+g+\kappa)s}] =$$

$$= \frac{B_0}{Y_0}(r+\pi+g)e^{-(r+\pi+g)s} - \frac{B_0}{Y_0}(r+\pi+\kappa)e^{-\kappa s}e^{-(r+\pi+g)s} = \frac{B_0}{Y_0}(r+\pi+g) - \frac{B_0}{Y_0}(r+\pi+\kappa)e^{-\kappa s} = 0$$

or

$$(r+\pi+g) = (r+\pi+\kappa)e^{-\kappa s}$$

or

$$\ln(r+\pi+g) = \ln(r+\pi+\kappa) - \kappa s \tag{9}$$

subject to the condition that the second order conditions

$$\frac{d(NPV)^2}{ds^2} = \kappa(r+\pi+\kappa)e^{-\kappa s}$$

is positive.

Since s features only on the cost side, we are talking about an expenditure minimization problem, i.e. finance whatever with the lowest cost possible. Given that we have κ>g, so that we get a positive s, we postulate a positive second order condition, since this assumption gives the optimum when we minimize costs.

The optimal debt maturity, s*, is derived from Eq. (9):

$$s^* = \frac{\ln(r+\pi+\kappa)-\ln(r+\pi+g)}{\kappa} = \frac{\ln(rn+\kappa)-\ln(rn+g)}{\kappa} \tag{10}$$

where rn=r+π, is the nominal interest rate and κ is assumed to be positive and greater than g.

Eq. (10) shows that the conventional principle of matching debt and maturity appears to be expressed by a relationship including the growth rate and the nominal interest rate.

Based on the method of Taylor series, Eq. (10) can also be expressed as

$$s^* = \frac{0.34\ln g + 0.24\ln rn \ln g - 0.34\ln\kappa - 0.24\ln rn \ln\kappa}{\kappa} \tag{11}$$

4. Estimation of the Model

Two points should be made with respect to the formula (11) defining the optimal maturity:

1) κ must be positive and greater than the growth rate of the economy for the maturity s to be positive. Normally, the debt auction commission cannot be so large, as no country would be willing to pay financial intermediaries its growth of output in every period.

This is not however the case if a broader definition of κ is adopted that includes the potentially adverse effect of a government bond issue on economic activity. This might occur when the rate of return of a debt-financed public investment would prove to be negative and hence, to crowd out private investment.

In theory, an increase in public investment financed by an issue of government bonds – at a given level of total savings – may cause interest rates to rise, the expected rate of return of private capital to decrease, and private investment to be crowded-out. On the other hand, public investment could create positive externalities, through promoting infrastructure, and hence could increase the productivity of private capital, with a crowding-in effect on private investment and economic performance.

To address both the question of whether public investment induces more or less private investment and, in general, the question of whether public investment has a significant effect on GDP, via computing macroeconomic rates of return, we adopt the methodology proposed by Pereira (2000), Pina and Aubyn (2005) and Afonso and

Aubyn (2008). Following their procedural steps, we estimate a small five-variable VAR model for Greece throughout both the entire period 1980-2009 and throughout some pre-determined subperiods. The variables in the VAR are the logarithmic growth rates of real public investment (GI), real private investment (PI), GDP (Y) and real taxes (T) as well as the change in real interest rates (R). Then, we are based on the impulse response function to compute:

a) The long-run accumulated elasticities of GDP with respect to public investment

$$\varepsilon_{GI} = \frac{d\ln(Y)}{d\ln(GI)}$$

b) The long-term marginal productivity of public investment

$$MP_{GI} = \frac{d(Y)}{d(GI)} = \varepsilon_{GI}\frac{Y}{GI}$$

c) The partial rate of return of public investment, r_1, from the solution of the relation

$$(1+r_1)^{20} = MP_{GI}$$

where the exponent "20" represents by assumption the average life for a capital good. Note that r_1 stands for the return on public investment when the relevant crowding-in or crowding-out effects of this public project are not taken into consideration.

d) The rate of return of total investment (originated by an impulse to public investment) r_2:

$$(1+r_2)^{20} = MP_I$$

where MP_I is the marginal productivity of total investment

$$MP_I = \frac{d(Y)}{d(GI)+d(PI)} = \frac{1}{(MP_{GI})^{-1}+(MP_{PI})^{-1}}$$

and MP_{PI} is the long-term marginal productivity of private investment given by a formula analogous to that for MP_{GI}. Note that r_2 stands for the rate of return of total investment (originated by an impulse to public investment), when crowding-in or crowding-out effects are accounted for.

In the estimation of the VAR, all variables are used in real terms and the chosen VAR order was selected with the Akaike and the Schwarz information criteria. The diagnostic tests showed that the null hypothesis of no serial residual correlation and normality could not be rejected. A dummy variable was also included taking the value of 1 in the period 2002-2009 and zero otherwise to capture the break in the series due to the introduction of euro in Greece.

Estimates of the accumulated responses of the VAR variables to public investment innovations reveal that the partial rate of return of public investment is negative (-4.2%) while the corresponding total rate of return is lower than the partial one (-5.2%). The corresponding rates of return for the subperiods range between -2.3% and -6.8%. These findings support the view that public investment leads to serious crowding-out effects with an adverse impact on output. The negative value of the total rate of return of public investment can be interpreted as increasing the value of κ. This increase was found to exceed the growth rate, g.

2) A second difficulty in estimating the maturity formula (11) is that optimal maturity is taken to depend on the growth rate and the nominal interest rate (given the auction fees), all of them being treated as exogenous. Thus, one of the problems arising in interpreting (11) is that changes in growth rate (interest rate) may be correlated with changes in interest rate (growth rate) or other explanatory variables not included in (11), so that the effect of the variable considered on maturity may yield a significant coefficient, despite that there is no causal relation running from it to the maturity structure. The sources of correlation may be either an omitted variable bias or the missing impact of other unspecified macroeconomic variables.

In addition to the omitted variable bias, tests conducted for autocorrelation proved to be significant at the 5 percent level. To resolve these matters, we opted for specifying three equations, (nominal interest rate, growth rate and deficit to GDP ratio). The latter variable proved to significantly affect the other two, in preliminary tests. Therefore, we build up a system including the above three equations and one identity, describing the maturity structure. This equation system is then simultaneously estimated to yield the optimal maturity horizon of the Greek public debt over the period 1980-2009[5].

Given the need to specify distinct relationships for each of the three determinants of maturity, the issue of choosing the appropriate explanatory variables for these determinants has been a topic of much debate. Contributions to the development of such an empirical work include:

1) Checherita and Rother (2010), Misztal (2010), Choong, Lau, Khim-Sen and Puah (2010), Schclarek (2005), Cohen (1999), Deshpande (1997), Elmendorf and Mankiw (1998), Lin and Sosin (2001), Abbas (2005) and Sachs and Warner (1995), who argue that public debt to GDP ratio, external balance to GDP ratio, budget balance, real interest rate and inflation rate constitute the main explanatory variables of growth rate.

2) Orr, Edey and Kennedy (1995), Mishkin (1981), Howe and Pigott (1991*)*, Allen (1992), Baxter (1994), Kandel, Ofer and Sarig (1996), Upper and Worms (2003), Deutsche Bundesbank (2001), Krämer (1996), Kahn and Farrell (2002), Barth and Bradley (1989), Barro and Sala-i-Martin (1990), Elmendorf (1996), Feldstein (1986) and Laubach (2009) who have found that debt/GDP and deficit/GDP ratios, inflation and growth rates, money supply/GDP, external

[5] For the estimates of the budget balance-GDP ratio, the growth rate and the nominal interest rate thirty different base years (i.e. all the sample years) will be used to test the robustness of the results of the equation system to alternative initial values.

balance/GDP, investment/GDP and private consumption/GDP ratios, unemployment rate and nominal effective exchange rate have a statistically significant effect on nominal interest rate.

3) Woo (2003), Cebula (2003), Gali and Perotti (2003) and Giuliodori and Beetsma (2008), who have found that the growth rates of GDP and inflation, liquid liabilities, money supply, real exchange rate, interest payments on debt, investment spending, tax revenue, internal revenue allocation, budget surplus, the ratio of pensioners to total population, foreign trade terms, financial depth, the size of the public debt, institutions and political factors have a statistically significant effect on budget balance.

The specifications used in the present study are derived from the aforementioned direct empirical assessments of the determinants of the budget balance-GDP ratio, the growth rate and the nominal interest rate. Given that the theoretical positions discussed in section 2 proved to be quite diverse, the above empirical assessments of the explanatory variables of maturity seem to be more promising in providing a socially optimal direction for the study of debt policy issues. No doubt, the advantage of estimating (11) in a single equation framework is that one can obtain the overall effect directly. However, the disadvantage is that one cannot get separate estimates of a large vector of macroeconomic factors affecting the decision making process in choosing the appropriate maturity structure. In addition, the collinearity problem may lower precision in the estimation of (11).

Evidently, there appears to exist in the literature a long array of explanatory variables for each of the three determinants of maturity. For a robust specification process, each of the corresponding (budget balance, growth rate, nominal interest rate) functions must fit the data well on the basis of the criteria of coefficient of determination, standard error of the estimate, expected signs and magnitudes of the coefficients.

The first step in our analysis is to test the data for the presence of unit roots. We adopt the Dickey-Fuller (DF) and the Augmented Dickey-Fuller (ADF) tests. Using a 5 percent critical value, we find that only three series (private consumption to GDP, external balance to GDP and the growth rate of GDP to labour force) strongly reject the unit root[6]. Our conclusion is therefore that most of the series are integrated of order one or order two.

The next step is to follow the lead of other researchers and adopt the method suggested by Pesaran, Shin and Smith (2001).

To resolve the problems of simultaneous equation bias, originating from a potential two-way causation that may run between each of the dependent variables and some of the corresponding explanatory variables and the correlation between the explanatory variables, we build-up a three-equation system augmented by the maturity identity (11) and to estimate it by using the Three-Stage Least Squares (3SLS) method.

The information set for starting the econometric analysis separately for each of the three functions contains all variables mentioned above and reviewed in existing literature. The approach to be followed in the present paper aims at ruling out the

[6] To conserve space, unit root tests are not reported here, but they are available from the authors on request.

possibility of getting results which may be biased due to the omission of relevant variables or results which may give spurious correlations. To exhaust the discussion of all the possible relationships, a large number of explanatory-variable subsets was tested by employing the Autoregressive Distributed Lag Model (ARDL) of Pesaran et al. and the functional form with the best "goodness-of-fit" performance was chosen. The mostly preferable form of each of the three functions is presented below:

1) Function of growth rate

$$\ln(g_t) = a_0 + a_1 dummy + a_2 \ln(\frac{D_t}{Y_t}) + a_3 \ln(\frac{B_t}{Y_t}) + a_4 \ln(rn_t) + a_5 \ln(\frac{EXB_t}{Y_t}) + \mu_t \quad (12)$$

where EXB is the external balance

The instruments used were among others constant and lagged values of primary budget balance-GDP ratio, public debt-GDP ratio, growth rate, inflation rate, nominal effective exchange rate, money supply-GDP ratio, external balance-GDP ratio, private consumption-GDP ratio, private investment-GDP ratio and unit labour cost.

2) Function of Nominal Interest Rate

$$\ln(rn_t) = b_0 + b_1 dummy + b_2 \ln(\frac{M_t}{Y_t}) + b_3 \ln(\frac{D_t}{Y_t}) + b_4 \ln(NEER_t) + b_5 \ln(W_t) + b_6 \ln(g_t) + b_7 \ln(\frac{B_t}{Y_t}) + \kappa_t \quad (13)$$

where M is the money supply, NEER is the nominal effective exchange rate and W is the unit labour cost

The instruments used were among others constant and lagged values of primary budget balance-GDP ratio, public debt-GDP ratio, growth rate, nominal effective exchange rate, money supply-GDP ratio, unit labour cost, inflation rate, external balance-GDP ratio, private consumption-GDP ratio and private investment-GDP ratio.

3) Function of Budget Balance

$$\ln(\frac{B_t}{Y_t}) = c_0 + c_1 dummy + c_2 \ln(\frac{TAX_t}{Y_t}) + c_3 \ln(\frac{PREXP_t}{Y_t}) + c_4 \ln(g_t) + c_5 \ln(rn_t) + c_6 \ln(\frac{D_t}{Y_t}) + u_t \quad (14)$$

where TAX is tax revenues and PREXP is primary expenditures

The instruments used were among others a constant and the lagged values of primary budget balance-GDP ratio, public debt-GDP ratio, tax revenues-GDP ratio, primary expenditures-GDP ratio and growth rate, nominal effective exchange rate, money supply-GDP ratio, external balance-GDP ratio, private consumption-GDP ratio, private investment-GDP ratio, interest payments-GDP ratio and unit labour cost.

In the above econometric model, the aim is to provide "stable" estimates over the entire sample period. One might of course be surprised if these relations are really stable at all. For instance, nominal interest rates before and after the euro introduction should be described by different statistical processes. Adopting euro has been beneficial to remove inflationary expectations. Discipline has also been imposed on the government to run budget deficits of less than 3 percent of GDP, even though this was not always respected. Since such institutional constraints may change the relation between growth, interest rates and the budget, we have introduced dummy variables in the above three relationships, taking the value of 1 for the post-euro period and zero otherwise.

Table 1 displays estimation results from Eqs. (12) to (14).

Table 1
ARDL long-run coefficients of the three-equation system

Explanatory variables	Coefficients	Standard errors	t-statistic [p-value]
1) Dependent variable is $\ln(g_t)$			
$\ln(D_t/Y_t)$	-0.12157	0.091782	-1.3246[0.200]
$\ln(B_t/Y_t)$	-0.13005	0.09157	-2.5147[.050]
$\ln(rn_t)$	-0.82292	0.36455	-2.2574[0.035]
$\ln(EXB_t/Y_t)$	-0.36673	0.24543	-1.4942[0.151]
C	0.18545	0.085023	2.1811[0.041]
dummy	-0.0034627	0.0028452	-1.2170[0.238]
2)Dependent variable is $\ln(rn_t)$			
$\ln(D_t/Y_t)$	0.55388	0.31224	1.7739[.094]
$\ln(g_t)$	-0.69646	0.35180	-1.9797[.064]
$\ln(M_t/Y_t)$	-0.67317	0.35188	-1.9131[.073]
$\ln(NEER_t)$	-0.062345	0.079144	-0.78774[.442]
$\ln(W_t)$	0.067933	0.52185	0.13018[.898]
$\ln(B_t/Y_t)$	-0.58563	0.26298	-2.2269[.040]
C	0.15462	0.18876	0.81911[.424]
dummy	-.018297	.0091426	-2.0013[.062]
3)Dependent variable is $\ln(B_t/Y_t)$			
$\ln(TAX_t/Y_t)$	2.5528	0.52271	4.8837[0.000]
$\ln(PREXP_t/Y_t)$	-0.34438	0.18422	-1.8694[0.080]
$\ln(g_t)$	-0.84319	0.49019	-1.7202[0.105]
$\ln(rn_t)$	1.0190	0.49737	2.0488[0.057]
$\ln(D_t/Y_t)$	-0.66735	0.35220	-1.8948[0.076]
C	-0.32185	0.085266	-3.7746[0.002]
dummy	0.0025112	0.0037934	0.66200[0.517]

Table 2
ARDL Error Correction coefficients of the three-equation system

Explanatory variables	Coefficients	Standard errors	t-statistic [p-value]
1) Dependent variable is $\Delta\ln(g_t)$			
$\Delta\ln(D_t/Y_t)$	-0.096062	0.071278	-1.3477[0.192]
$\Delta\ln(B_t/Y_t)$	0.29527	0.15237	1.9378[0.066]
$\Delta\ln(rn_t)$	-0.65023	0.23350	-2.7847[0.011]
$\Delta\ln(EXB_t/Y_t)$	-0.28977	0.21023	-1.3784[0.183]
ΔC	0.14653	0.051875	2.8246[0.010]
dummy	-0.0027360	0.0020011	-1.3673[0.186]
EC(-1)	-0.79015	0.22596	-3.4968[0.002]
R^2=0.56279 Regression standard error =0.018252		Adjusted R^2=0.40977 F(6,21) statistic=4.2908[0.006] D-W statistic= 2.0691	
2) Dependent variable is $\Delta\ln(rn_t)$			
$\Delta\ln(D_t/Y_t)$	0.20190	0.24313	0.83040[.417]
$\Delta\ln(g_t)$	-0.55106	0.27219	-2.0245[.057]
$\Delta\ln(M_t/Y_t)$	-0.53263	0.27365	-1.9464[.067]
$\Delta\ln(NEER_t)$	-0.049329	0.061019	-0.80841[.429]
$\Delta\ln(W_t)$	0.053751	0.40940	0.13129[.897]
$\Delta\ln(B_t/Y_t)$	0.35867	0.20602	1.7409[.098]
ΔC	0.12234	0.14520	0.84253[.410]
dummy	-0.014477	0.0068680	-2.1079[.049]
EC(-1)	-0.79123	0.14872	-5.3202[.000]
R^2=0.76492 Regression standard error =0.020079		Adjusted R^2=0.62664 F(8,19)statistic=6.9146[0.006] D-W statistic= 2.0441	
3) Dependent variable is $\Delta\ln(B_t/Y_t)$			
$\Delta\ln(TAX_t/Y_t)$	1.9972	0.28961	6.8963[0.000]
$\Delta\ln(PREXP_t/Y_t)$	-0.56894	0.078891	-7.2117[0.000]
$\Delta\ln(g_t)$	0.17254	0.15804	1.0917[0.288]
$\Delta\ln(rn_t)$	0.23938	0.12682	1.8876[0.074]
$\Delta\ln(D_t/Y_t)$	-0.30211	0.13158	-2.2960[0.033]
ΔC	-0.14570	0.066337	-2.1964[0.040]
dummy	0.0011368	0.0015622	0.72772[0.475]
EC(-1)	-0.45271	0.12911	-3.5063[0.002]
R^2=0.91234 Regression standard error =0.010339		Adjusted R^2=0.85207 F(7,20) statistic=23.7886[0.000] D-W statistic=2.0422	

In general, the three equations appear to fit the data well, as the adjusted coefficients of determination are quite high, many estimated coefficients are significant, and there is no obvious sign of autocorrelation in the residuals, as judged by the values of the Durbin-Watson statistic.

Various model evaluation diagnostic tests for the residuals of each of the three estimated equations were conducted. They included tests for error autocorrelation, using LM(1) and LM(4) tests, and model misspecification (Ramsey's RESET) test, a residual normality test (Jarque-Bera), the conventional autoregressive conditional heteroscedasticity (ARCH) test and Breusch-Pagan-Godfrey's heteroscedasticity test. All diagnostic tests indicated that the residuals are Gaussian without any strong evidence of autocorrelation and heteroscedasticity.

To determine the optimal debt maturity structure for Greece, a system of equations is constructed, containing the maturity identity (11) and the three functional forms specifying the growth rate, the nominal interest rate and the budget balance-GDP ratio as described by Eqs (12), (13) and (14), respectively. The equation system is then estimated using the 3SLS method, with the fitted values of the determinants of the maturity identity (11) being employed, in lieu of the actual (observed) data. This process allows us to concentrate on all the crucial macroeconomic (fiscal and monetary) factors which influence government decisions on designing suitable debt-maturity policies. The 3SLS estimates are reported in Table 3.

The main inference from the inspection of Table 3 is that most of the coefficients on growth rate, nominal interest rate and budget balance enter significantly with their sign conforming to the theoretical expectations, although some of them fail to enter significantly at a 5 percent confidence level. In general, however, the fit of the equations is good, as evidenced by the significance of most of the estimated coefficients and the adequately high explanatory power (except for the growth rate equation) indicated by the adjusted R^2. Diagnostic tests conducted for tracing higher-order autocorrelation, serial dependence of regression residuals, functional form misspecification, simultaneous equation bias, homoscedasticity and non-normal residuals indicated that these well-known pitfalls in empirical modeling are absent in the system of equations considered.

The last step in our analysis is to introduce the fitted values of the three-equation system – i.e. the 3SLS coefficient estimates of Table 3 - in the maturity relationship (11) to determine the optimal values of the debt maturity structure of Greece over the period 1980-2009. The estimated optimal values of maturity and the corresponding actual/(observed) data are displayed in Table 4.

For comparison purposes, Fig. 5 plots the time path of both the optimal and the actual values of the maturity structure of Greece. Though considerable caution needs to be taken in interpreting the results, they nevertheless may be useful in making broad judgments on the overall patterns of optimal and actual maturity. A mere inspection of Table 4 and Figure 5 appears to provide a benchmark for comparing the two time paths and to lend support to the argument that government operations on debt management have been conducted inefficiently over the period 1987-2009. This is so, because the optimal maturity structure is shown to fluctuate far below the actual one. Many of government's fiscal and monetary policies proved to distort economic incentives and lower the productivity of the Greek economy. In what follows, we present some aspects of the distorting role of the government in the stabilization and growth process.

Table 3
3SLS estimates of the equation system

EQUATION SYSTEM

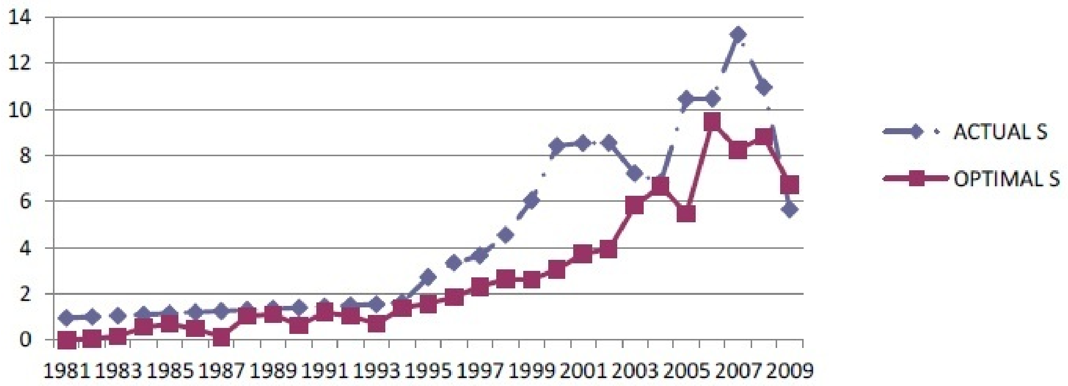
Period 1981-2009
Methodology 3SLS

Explanatory variables	Coefficients	Standard Errors	t-statistic [p-value]
EQUATION 1: $\ln(g_t)=a_0+a_1 dummy+a_2\ln(D_t/Y_t)+a_3\ln(B_t/Y_t)+a_4\ln(rn_t)+a_5\ln(EXB_t/Y_t)+\mu_t$			
Dependent variable is $\ln(g_t)$			
C	-0.007345	0.036275	-0.202480[0.840]
dummy	-0.003735	0.002802	-1.333111[0.187]
$\ln(D_t/Y_t)$	0.125896	0.120067	1.048546[0.298]
$\ln(B_t/Y_t)$	0.006851	0.131871	0.051952[0.958]
$\ln(rn_t)$	-0.317879	0.141274	-2.250088[0.027]
$\ln(EXB_t/Y_t)$	-0.392726	0.217941	-1.801983[0.076]
R^2=0.2788		Adjusted R^2=0.1149	
Standard Error=0.0210		DW statistic=1.3490	
EQUATION 2: $\ln(rn_t)=b_0+b_1 dummy+b_2\ln(M_t/Y_t)+b_3\ln(D_t/Y_t)+b_4\ln(NEER_t)+b_5\ln(W_t)+ +b_6\ln(g_t)+b_7\ln(B_t/Y_t)+\kappa_t$			
Dependent variable is $\ln(rn_t)$			
C	0.259633	0.179136	1.449361[0.152]
dummy	-0.015131	0.011840	-1.277979[0.205]
$\ln(M_t/Y_t)$	-1.078390	0.434880	-2.479743[0.015]
$\ln(D_t/Y_t)$	0.675354	0.314173	2.149627[0.035]
$\ln(NEER_t)$	-0.131226	0.071842	-1.826601[0.072]
$\ln(W_t)$	-0.396148	0.636869	-0.622024[0.536]
$\ln(g_t)$	-0.960365	0.362491	-2.649345[0.010]
$\ln(B_t/Y_t)$	0.108284	0.238997	0.453075[0.652]
R^2=0.8294		Adjusted R^2=0.7697	
Standard Error=0.0319		DW statistic=1.7762	
EQUATION 3: $\ln(B_t/Y_t)=c_0+c_1 dummy+c_2\ln(TAX_t/Y_t)+c_3\ln(PREXP_t/Y_t)+c_4\ln(g_t)+c_5\ln(rn_t)+c_6\ln(D_t/Y_t)+u_t$			
Dependent variable is $\ln(B_t/Y_t)$			
C	-0.374741	0.071114	-5.269562[0.000]
dummy	-0.008846	0.002263	-3.908340[0.000]
$\ln(TAX_t/Y_t)$	1.275417	0.507537	2.512954[0.014]
$\ln(PREXP_t/Y_t)$	-0.694225	0.145076	-4.785247[0.000]
$\ln(g_t)$	0.075808	0.293483	0.258304[0.797]
$\ln(rn_t)$	-0.221865	0.148091	-1.498167[0.139]
$\ln(D_t/Y_t)$	0.537512	0.219006	2.454325[0.016]
R^2=0.7475		Adjusted R^2=0.6753	
Standard Error=0.0258		DW statistic=1.1616	

Table 4
Optimal and actual values of debt maturity, Greece

	OPTIMAL MATURITY	**ACTUAL MATURITY**
1981	0.03	0.95
1982	0.05	1.00
1983	0.16	1.05
1984	0.56	1.1
1985	0.69	1.15
1986	0.48	1.2
1987	0.14	1.25
1988	1.04	1.3
1989	1.11	1.35
1990	0.63	1.4
1991	1.19	1.45
1992	1.04	1.5
1993	0.71	1.55
1994	1.38	1.63
1995	1.57	2.72
1996	1.85	3.34
1997	2.32	3.65
1998	2.63	4.55
1999	2.62	6.05
2000	3.07	8.43
2001	3.73	8.54
2002	3.95	8.55
2003	5.84	7.22
2004	6.68	6.85
2005	5.47	10.46
2006	9.45	10.47
2007	8.25	13.25
2008	8.82	10.96
2009	6.74	5.66
Average	**2.83**	**4.43**

Figure 5. Optimal and actual values of debt maturity,s



Sources: Results from Table 4 for optimal values of maturity and Ministry of Finance of Greece for actual values of maturity. The initial values for the ratio of budget balance to GDP are those of 1981 (base year), but the results are approximately the same, regardless of the year used.

The disincentives created by the need to service an increasing public debt led to misallocation of resources. The result was to mitigate, if not totally offset, the positive aspects of the debt-induced increase in available domestic resources. Using the 3SLS parameter estimates of the three-equation system (and the corresponding fitted values of the variables), we find an average value of the partial derivative of optimal maturity with respect to growth rate equal to roughly -1 (see Table 5), implying that one percentage point increase in the growth rate leads, *ceteris paribus*, to an approximately one-year decrease in optimal maturity. Other studies, such as those of Ferreira (2009) and Choong et al. (2010), also ascertain that this relation is negative. However, there are studies – see for example Misztal (2010) – which find out that there is a positive relation between debt maturity and growth rate.

Given the negative productivity of debt-financed government expenditure, the partial derivative of optimal maturity with respect to public debt bears a negative sign with an average value equal to -0.89, indicating that a one-percentage point increase in the share of public debt to GDP is associated with a 0.89 decrease in optimal maturity on the average. Studies which agree with this result are those of Missale and Blanchard (1994), Drudi and Giordano (2000), Goldfajn (1995). However, there are studies, such as those of Alesina, Prati and Tabellini (1990), Calvo and Guidotti (1992) and De Haan et al (1995), which claim that there is a positive association between the debt/GDP ratio and debt maturity. As can be easily seen in Table 4 and Figure 5, between 1981 and 2009, the average actual maturity of the Greek public debt, compared with the optimal maturity, rose by a factor of 4, instead of converging to unity. The implication of this divergence is that the social cost from the negative contribution of debt-funded public activities is distributed along a much longer time period, embracing "innocent" future generations.

On similar grounds, by estimating the effects of fiscal balance, taxation, government spending, interest payments, inflation rate, interest rate and external balance on optimal maturity, one may better observe the magnitude of the distortionary influences of public debt management. For example, the estimated values of the derivative of optimal maturity with respect to changes in the budget balance – reported in Table 5 – serve as a proxy for the government-induced excess burden, resulting from the shift of resources out of productive uses into unproductive ones: One percentage point increase in the ratio of budget balance (surplus) to GDP decreases optimal maturity by 0.48 basis points on the average, over the period 1981-2009. However, the actual maturity level remained substantially higher than optimal maturity throughout the period considered. There are studies, such as those of Bacchiochi and Missale (2005), Blundell-Wignall and Slovik (2011), Leong (1999), Ferreira (2009) and Choong et al (2010), which argue that as the primary surplus increases, public debt maturity increases, too. However, other studies, such as those of Missale (1998) and Hawkesby and Wright (1997), claim that this relation is negative.

The same arguments apply when we analyze the effects of marginal changes in the remaining determinants of optimal maturity and set them against movements in optimal maturity, as shown in Table 5. For instance, a one-percentage point increase in the inflation rate is associated with a 1.09 increase in optimal maturity on the average. Some studies which are in favor of long-run bonds when inflation increases are those of Missale (1997), Leong (1999), Gale (1990), Calvo and Guidotti (1992) and Barro (1998). However, other studies, such as those of Missale (1998), Hawkesby and Wright (1997), Falcetti and Missale (2002) and Alesina, De Broeck, Prati and Tabellini (1992), claim that the government must issue short-term bonds when the inflation rate increases.

The results also show that a one-percentage point increase in the real interest rate is associated with a 0.41 decrease in optimal maturity. Other studies which support this result are those of Nam and Radulescu (2010), Missale (1998), Hawkesby and Wright (1997) and Goldfajn (1995). However, there are studies, such as those of Alesina, Prati and Tabellini (1990), Calvo (1988) and De Haan et al (1995), which claim that there is a positive relation between debt maturity and real interest rate.

In summarizing the results, Table 5 reveals that marginal increases in the debt/GDP, fiscal balance/GDP and tax revenues/GDP ratios, the growth rate, the real interest rate and the interest payments lead to a decline in optimal maturity, whereas marginal increases in the remaining determinants are associated with small-scale increases in optimal maturity. These results sharply contrast with the actual maturity policy of lengthening the duration of public debt, that had been adopted by the Greek government throughout the post-1987 period.

Table 5
Values of partial derivatives of optimal maturity with respect to its main determinants

	ds/d(D/Y)	ds/d(B/Y)	ds/d(TAX/Y)	ds/d(PREXP/Y)	ds/d(g)	ds/d(rn)	ds/d(EXB/Y)
1981	-0.561	-0.226	-1.424	0.947	-0.559	0.290	0.587
1982	-0.441	-0.169	-1.064	0.712	-0.412	0.229	0.473
1983	-0.696	-0.279	-1.727	1.145	-0.668	0.363	0.781
1984	-2.329	-0.943	-5.882	3.919	-2.294	1.238	2.633
1985	-1.436	-0.593	-3.648	2.405	-1.422	0.789	1.656
1986	-0.525	-0.217	-1.330	0.889	-0.536	0.291	0.600
1987	-0.497	-0.211	-1.305	0.874	-0.522	0.281	0.580
1988	-0.474	-0.229	-1.269	0.725	-0.510	0.280	0.581
1989	-0.426	-0.212	-1.173	0.661	-0.465	0.255	0.551
1990	-0.394	-0.204	-1.147	0.649	-0.470	0.252	0.566
1991	-0.361	-0.185	-1.063	0.619	-0.439	0.231	0.526
1992	-0.342	-0.178	-1.044	0.610	-0.436	0.220	0.512
1993	-0.324	-0.171	-1.014	0.593	-0.426	0.218	0.501
1994	-0.314	-0.164	-1.010	0.612	-0.431	0.226	0.493
1995	-0.319	-0.168	-1.014	0.605	-0.428	0.236	0.504
1996	-0.329	-0.173	-1.046	0.632	-0.442	0.251	0.528
1997	-0.337	-0.176	-1.045	0.629	-0.444	0.265	0.528
1998	-0.379	-0.196	-1.160	0.703	-0.495	0.302	0.602
1999	-0.381	-0.198	-1.165	0.706	-0.496	0.312	0.610
2000	-0.310	-0.163	-0.952	0.574	-0.406	0.258	0.518
2001	-0.436	-0.235	-1.354	0.807	-0.573	0.365	0.724
2002	-0.629	-0.345	-1.960	1.158	-0.828	0.527	1.048
2003	-0.919	-0.514	-2.882	1.684	-1.218	0.774	1.505
2004	-1.297	-0.750	-4.155	2.397	-1.765	1.109	2.101
2005	-1.750	-1.015	-5.643	3.292	-2.429	1.522	2.832
2006	-2.153	-1.267	-7.055	4.105	-3.027	1.899	3.613
2007	-2.434	-1.450	-8.073	4.677	-3.458	2.184	4.296
2008	-2.584	-1.591	-8.759	4.978	-3.765	2.361	4.708
2009	-2.655	-1.745	-9.349	5.101	-3.984	2.467	4.774
AVERAGE	**-0.898**	**-0.482**	**-2.749**	**1.635**	**-1.150**	**0.689**	**1.377**

5. Concluding remarks

In this paper, we argue that an analytical approach to the determination of the optimal debt-maturity structure that takes into account a welfare maximization (or a social loss minimization) process helps to generate important insights in debt management policy. To substantiate this argument, we constructed a three-equation system that estimates the complicate relationship of optimal maturity with its most significant determining factors. The underlying reason is that a comparison of the estimated optimal maturity structure with the actual one adopted by the Greek government could provide valuable information as to the potential existence of drawbacks in the design and implementation of fiscal policies concerning the financing of budget deficits.

The model was estimated and tested for Greece over the pre-debt-crisis period 1980-2009. The main finding from the econometric investigation was that a large gap appeared to exist between the optimal and the actual maturity structure, which may be partly responsible for the post-2009 debt crisis in Greece.

The analysis uncovers empirical predictions of the basic debt management model that have not been previously investigated in the literature on this issue. Note, however, that the present study should be interpreted as a modest first step towards a more complete empirical assessment of optimal maturity. In fact, although our results appear promising, more work is needed to determine if the inferences reported in this paper are robust to alternative specifications of the model or to more representative data sets.

A final note is worth mentioning. The estimation in section 4 is based on three regressions, estimated with 3SLS. Clearly, there are several specifications possible for these three regressions. However, assessing how robust are our empirical conclusions for different specifications is not easy and this is a common problem that arises in many applied macroeconomic papers. To make an effort to support the view that our claims concerning the wide gap between the actual and the optimal debt maturity structure can be used to partly explain the debt crisis in Greece, we employed alternative regression specifications (2SLS, GMM), varying definitions of the gross rate of return on public investment, different interest rates (money market interest rates, central government bond yields, Maastricht criterion interest rates, 3-month rates, Euro yield curves, ECU interest rates), various inflation indices and so on. These changes failed to reject the basic finding of our study that the optimal maturity structure lies below the actual maturity structure.

In summary, though the literature has emphasized that government debt should be long term, here it is argued that minimizing costs may be a first objective of the debt management office. Based on this presumption we tried to investigate what the optimal maturity is. Rather than relying on a microfounded model, our approach gives us the ability to derive the maturity formula analytically and subsequently to estimate from the data all the important variables that enter into this expression. The gain is that, in contrast to theoretical models, nominal interest rates, growth rates, fiscal balances, etc. are taken from the data; hence, they capture in reduced form a number of complexities and moments which theoretical models are probably not able to match.

Appendix

Data sources

The data are annual covering the period 1980 to 2009. Gross Domestic Product, Inflation rate, External balance and Growth rate, come from the OECD database.
Nominal interest rate comes from the Eurostat database, Ameco.

Gross public debt and budget balance come from Ministry of Finance of Greece for the period 1980-1988 and from the database of Eurostat, Ameco for the period 1989-2009.

Interest payments come from Bank of Greece[7] and from OECD[8] for the period 1980-1987 and from the database of Eurostat, Ameco for the period 1988-2009.

Tax revenue and primary expenditures come from the OECD database for the period 1980-1987 and from the database of Eurostat, Ameco for the period 1988-2009.

The debt maturity (weighted average maturity of Greek public debt) comes from the Ministry of Finance, Greece, Department of Public Debt.

The original data have been deflated by the GDP Deflator (2000 = 100) taken from the OECD Database). Data expressed as a percentage of GDP (including negative values) are scaled up by 1.

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