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# Greece's Three-Act Tragedy: A Simple Model of Grexit vs. Staying Afloat Inside the Single Currency Area

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## Abstract

Against the backdrop of the Greek three-act tragedy, we present a theoretical framework for studying Greece's recent debt and currency crisis. The model is built on two essential blocks: first, erratic macroeconomic policymaking in Greece is described using a stochastic regime-switching model; second, the euro area governments' responses to uncertain macroeconomic policies in Greece are considered. The model's mechanism and assumptions allow either for a Grexit from the euro area or, conversely, the avoidance of Greece's default against its creditors. The model also offers useful guidance to understand key drivers of the long-winded negotiations between the Greek government and the "institutions".

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**Keywords:** Greece, sudden stop, euro, financial assistance programmes

**JEL-Classification:** F34, F45, H63

## 1. Introduction

The Greek debt crisis has received a great amount of attention from both academics and policymakers. Greece ran into difficulties and was placed under the financial market's spotlight in 2010. In the summer of 2009, a new government took power in Greece. At the time, the country was believed to have a fiscal deficit-to-GDP ratio of 4 per cent. However, after inspecting the expenditure and revenue data, the new government realized there had been a massive accounting fraud: the fiscal deficit-to-GDP ratio was not 4 per cent but rather 15 per cent. Given this fiscal shock, which as been the result of policy errors made by successive governments over several decades, memories of the Argentinian crises 2001-2002 were invoked. The subsequent first EUR 110 billion bailout package in May 2010 was born out of a constellation of fears. European Union leaders worried that a write-off of Greek debt would unleash Lehman-style international systemic spillovers and provoke an economic meltdown.<sup>1</sup> The austerity measures tipped Greece straight into recession. After five years, two bail-outs and a debt haircut in 2012, Greece's economy is around 25 per cent smaller than at its peak in 2008, unemployment stands at 26 per cent and public debt is nearly 180 per cent of GDP. The existing governance structure provides little foundation for success and the old diseases of an inefficient tax system, red tape and corruption have not been eliminated.<sup>2</sup> One reason for this is that many promised reforms have either been neglected or implemented piecemeal and reluctantly.<sup>3</sup>

After the election of the Syriza-led government in 2015 Greece again stood at the brink of debt default.

A substantial amount of political brinkmanship was employed to achieve a negotiated outcome, which aimed to see the Greek government agree to a reform package with the so-called "institutions", consisting of the European Commission, the European Central Bank (ECB) and the International Monetary Fund (IMF), in exchange for continued financial support. Given the dramatic deterioration in the economic situation, the Greek government finally applied for a new three-year programme from the European Stability Mechanism (ESM) and a deal was finally struck after a marathon all-night summit that paved the way to a 3<sup>rd</sup> Greek bailout in August 2015, subject to strict conditions.<sup>4</sup> The deal included loans of EUR 86 billion and a short-term economic stimulus plan for Greece. In return, the Greek government agreed to a number of structural reforms including pension cuts, VAT tax increases, the opening up of professions, the privatization of the electricity network and labour market reforms. A new privatization fund is to be set up, with the objective of eventually raising EUR 50

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<sup>1</sup> Blanchard (2014) has argued that macroeconomic policies should make avoiding dark corners a high priority.

<sup>2</sup> On the latest World Bank "Ease of Doing Business Index 2016" (<http://www.doingbusiness.org/reports/global-reports/doing-business-2016>) Greece ranks 60<sup>st</sup>, as the country with the very worst business environment in the EU, and far behind Iceland (12), Ireland (19), Portugal (23) and Spain (33).

<sup>3</sup> Rodrik (2014) has emphasized how difficult it may be to implement good governance and structural reforms in politically fragile countries.

<sup>4</sup> Refusal to strike a deal with the euro area would have terminated the ECB's emergency lending to Greek banks, sending them into insolvency. Such a course would have led to the implosion of the Greek economy.

billion, of which half will go towards recapitalizing Greek banks, a quarter on paying down debt and the remaining quarter on investment. Privatization is expected to raise up to EUR 6.4 billion between 2015 and 2017. The various structural reform programmes should lead to internal deflation and boost competitiveness.<sup>5</sup>

Against this background of episodes of crisis and turbulence, the remainder of the paper is set out as follows. In Section 2 the theoretical background is laid out. The model aims to shed light on the economic and political upheavals in Greece and their consequences. In particular, we consider how erratic macroeconomic policies could undermine Greece's euro area membership. Section 3 reports numerical model simulations which highlight the model's mechanism. Finally, we offer some concluding remarks and offer pathways for future research in Section 4.

## **2. A Simple Model of Grexit vs. Staying Afloat inside the Euro Area**

In this section we propose a new way of thinking about the Greek debt drama. In what follows, we make some conjectures about what strategies could be followed to do this. Emerging market and developing economies typically run current account deficits in order to smooth consumption intertemporally. The counterpart of these deficits is their dependence on capital inflows, which can suddenly stop. Indeed, since the early 1990s countries as diverse as Mexico, Russia, a group of East Asian countries, Brazil, Turkey and Argentina have all been hit by either currency or financial crises, or both. The boom-and-bust cycle left the countries in an overvalued position under a fixed exchange rate system. The "sudden stop" of capital inflows was almost always followed by a sharp contraction in gross domestic product.<sup>6</sup> How best to incorporate the key features of the three-act Greek tragedy described above into an analytical model is far from obvious. The paper presents a theoretical framework for studying Greece's recent debt crisis and how Grexit could occur. The novelty of the piece is that the Greek government's adherence to a sustainable debt path is modelled as a stochastic regime-switching model. In this way, the Greece's erratic behaviour is incorporated into the Eurozone's decision of whether to grant continued aid or force Greece out of the Eurozone. The stylized theoretical framework is tractable in terms of understanding its mechanism but rich enough to capture the salient facts that lie at the heart of the Greek debt crisis. The broad goal is to tackle a very

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<sup>5</sup> The evolution of the ECB's "Harmonized Competitiveness Index", based on unit labour costs ([https://www.ecb.europa.eu/stats/exchange/hci/html/hci\\_ulct\\_2014-10.en.html](https://www.ecb.europa.eu/stats/exchange/hci/html/hci_ulct_2014-10.en.html)), shows that Greece had indeed experienced one of the greatest losses in unit labour cost competitiveness prior to the start of the crisis, but from 2009Q4 to 2014Q4 unit labour cost competitiveness improved by 23 per cent. The considerable improvements in unit labour cost competitiveness were due to the massive drops in wages and salaries, which the "institutions" continued to insist upon with a view to improving the price competitiveness of Greek exports and import substitutes.

<sup>6</sup> Some observers have warned that Greece could turn into an Argentina, implying that the situation could get much worse (see, e.g., Reinhart, 2015). Others claimed that following Argentina into default and into a strong depreciation could help Greece to start a recovery (see, e.g., Krugman, 2015). Reinhart and Rogoff (2009) have documented that historically it has been quite common for sovereigns to default on their debts.

topical euro area issue. One of our ancillary goals here is to try to operationalize the vague concept of erratic macroeconomic policies and reform willingness. We begin by constructing a sudden-stop type model in which the readiness for fiscal and structural reforms in Greece and the willingness of the “institutions” to provide foreign loans interact.<sup>7</sup> Our starting point is the well-known equation for the dynamics of public debt:

$$(1) \quad \frac{dB_s}{ds} = G_s - T_s + r_b B_s,$$

where  $s$  denotes time,  $G_s$  is government expenditure,  $T_s$  denotes tax revenues and  $r_b$  is the effective interest rate on Greece’s government debt.<sup>8</sup> Thus, we exclude the possibility that the Greek government can borrow from the ECB to finance its deficit. The term  $(G_s - T_s)$ , i.e. the difference between total expenditure and revenue, is the primary surplus/deficit. It is the primary surplus/deficit that is of central concern for economic policy.

In order to pin down the determinants of the growth in the public debt-to-GDP ratio, we use the definition  $b_s = \frac{B_s}{P_s y_s}$ , where  $P_s$  is the domestic price level and  $y_s$  is real national income. By rearranging the budget identity, we then have the following differential equation for the dynamics of the deficit-to-GDP ratio:

$$(2) \quad \frac{db_s}{ds} = -\delta_s + (r_b - \pi - \eta_y)b_s$$

where  $\delta_s = -(G_s - T_s)/P_s y_s$  and thus positive (negative)  $\delta_s$  denotes a budget surplus (deficit),  $\pi = (1/P)(dP/ds)$  is the constant inflation rate and  $\eta_y = (1/y)(dy/ds)$  is the constant growth rate of GDP. Equation (2) explains the four key determinants of the growth rate of the debt-to-GDP ratio: (1) the government budget surplus/deficit ratio; (2) the real interest rate on public debt; (3) the growth rate of GDP; (4) the existing ratio of government debt to GDP.

Next, we move beyond the government’s budget identity. In colloquial terms, the phrase “sustainable sovereign debt” captures the notion of fiscal responsibility. To apply the term usefully in the currency crisis model context, it is important to be precise about what qualifies as sustainable fiscal policy. We define the decision rule as the public debt-to-GDP ratio  $b_s = B_s/(P_s y_s)$  at the end of the support package period  $s \in (t, \tau)$ , where  $\tau$  denotes the end of the financial assistance arrangement. With

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<sup>7</sup> Dynamic stochastic general equilibrium (DSGE) models are a conceivable modelling alternative. The common practice is to solve and estimate linearized DSGE models with Gaussian shocks. These models have tangible micro foundations and are now widely used for empirical research in macroeconomics. Because these models are built on real business cycle foundations, political economy issues play a distinctly second fiddle role, if they play any role at all. Therefore, it remains challenging for policymakers to use them in the formulation of policies.

<sup>8</sup> The sustainability of the Greek debt was an important issue in the negotiations on how to resolve the Greek crisis. Correspondingly, cutting the effective interest burden on the Greek sovereign debt was an important part of the various assistance programmes.

expected inflation rate  $\pi$  and real income growth rate  $\eta_y$ , the value of  $b_\tau$  can be obtained via equation (2). Multiplying both sides of equation (3) by  $e^{-(r_b-\pi-\eta_y)(s-t)}$ , rearranging and integrating from  $s = t$  to  $s = \tau$  yields the following relationship between  $b_\tau$  and  $\delta_s$ :

$$(3) \quad b_\tau = e^{(r_b-\pi-\eta_y)(\tau-t)}(b_t + v),$$

where

$$(4) \quad v = - \int_{s=t}^{\tau} \delta_s e^{-(r_b-\pi-\eta_y)(s-t)} ds.$$

The value  $v$  in equation (4) denotes the net present value of the reduction of public debt subject to the government budget surplus/deficit ratio  $\delta_t$ . The mind-focusing sustainability measure in equation (3) is simple and intuitive, yet rigorous, and distils a wealth of information into a single measure. By boiling the complexities of surveillance down into a single, comprehensible number, it gives the institutions something simple to aim at and also something against which they can measure the success of the Greek government's endeavours. Hereinafter, we assume that the expected  $b_\tau$  serves as a basis for the decision making of the institutions. Clearly,  $b_\tau$  depends upon the government budget surplus/deficit ratio  $\delta_s$ .

We turn our attention now to political uncertainty, which takes centre stage in the modelling framework. Political uncertainty is a vague concept and difficult to model. Historical experiences are an imperfect guide to the future and ought not to be seen as a clear precedent or template. However, as Greece's pledges to the institutions were never fulfilled in the past, it is doubtful whether the Greek authorities will hit its budget targets in the future. This was the dilemma the European governments faced. What does this mean in detail? To focus the analysis on the uncertainty of the fiscal process, we assume that the Greek government budget surplus/deficit-to-GDP ratio  $\delta_s$  follows a Markov switching process.<sup>9</sup> The Markov switching approach captures what the Greek government has long denied: that Greece must choose between the creditors' path of sound fiscal policies or leaving the euro. This choice is central to our storyline and it is this ingredient that constitutes the key architecture of our

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<sup>9</sup> All uncertainty is associated with the fiscal policy process. For simplification and to sharpen the focus of the model, other stochastic shocks have been omitted. Furthermore, to keep the analysis transparent, the adequacy of the recommendations for action from the "institutions" are taken as given and are not scrutinized. For example, one might argue that austerity in a weak economy could be self-defeating as fiscal tightening curtails economic growth. One might also argue that Greece has a debt overhang. Finally, while structural reforms could possibly create a favourite environment for growth in the long term (IMF, 2015c, pp. 104–107), an immediate payoff is doubtful given the largely unchanged governance structure. These topics of discussion indicate that ongoing membership in the euro area does not necessarily mean a "Grecovery". For a thorough examination of the channels through which structural reforms may promote growth and the optimal sequencing of reform, see Christiansen et al. (2013) and Eggertsson et al. (2014).

theoretical setup. For this, the deterministic growth of public debt in equations (2) - (4) is replaced by a nonlinear stochastic process. In other words, we propose a risk-based view of macroeconomic policies in Greece. In the sustainable Markov switching state (denoted by “0”), the Greek government generates a sufficient government budget surplus to remain solvent and thus negative  $v$ , leading to  $b_\tau < b_t$ . In the second Markov switching state (denoted by “1”), the Greek government chooses an unsustainable fiscal policy trajectory, leading to a further increase in public debt and thus positive  $v$ , with  $b_\tau > b_t$ . When fiscal policy is unsustainable, policies should change. This is simply the well-known transversality condition ruling out Ponzi schemes. The Greek authorities could, for example, cut spending, increase tax revenues and implement non-budgetary policies that promote future growth. In a nutshell, we have:

$$(5) \quad \delta_s = \begin{cases} \delta^1 < 0: & \text{unsustainable fiscal policy regime} \\ \delta^0 > 0: & \text{sustainable fiscal policy regime} \end{cases}$$

where for simplicity we assume that  $\delta^0$  and  $\delta^1$  are both constants. Although a reduced form, the Markov switching model is a flexible framework for modelling the political upheaval in Greece and its two-way interaction with the institutions. The two-state first-order Markov chain  $state_s \in \{0,1\}$  is characterized by the transition matrix  $P \equiv (q_{ij}) \equiv \Pr[state_s = j | state_{s-\Delta s} = i]$  for  $i, j = 0,1$  which can be written concisely as:

$$(6) \quad P = \begin{pmatrix} 1 - p_{01} & p_{01} \\ p_{10} & 1 - p_{10} \end{pmatrix} = \begin{pmatrix} p_{00} & p_{01} \\ p_{10} & p_{11} \end{pmatrix},$$

where  $p_{01}$  denotes the probability of jumping from state “0” to state “1” and  $p_{10}$  is the probability of jumping from state “1” to state “0”. We take an agnostic viewpoint and assume that the switching probabilities are exogenous. In other words, the probabilities are assumed to be independent from other events in the economy.<sup>10</sup> Equation (6) governs the manner in which regime shifts occur. As the regime is a hidden state variable, the institutions face a signal extraction problem. In other words, the institutions incorporate the possibility of a political economy failure and the shift to a different fiscal regime when deciding on future assistance programmes.<sup>11</sup>

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<sup>10</sup> The volatility of the political system is clearly not an exogenous variable. Arguably, as regime transitions occur exogenously, they can be regarded as a measure of our ignorance rather than our understanding. Yet, the impact of political uncertainty is interesting, regardless of the actual causes. Our approach follows Zellner’s (1992) “KISS” (i.e. keep it sophisticatedly simple) principle. Ours is not the first paper to show that many economic variables can be modelled with the aid of Markov switching models. There is an extensive empirical literature modelling economies as following regime-switching processes. For background, see Hamilton (1989) and Kim and Nelson (1999) and the references contained therein. These findings motivate models that build regime-switching policy rules directly into theoretical frameworks.

<sup>11</sup> As shown in Appendix A, fiscal policy has been conducted in a stop-and-go fashion over the past decade and thus the Markov switching process is able to capture the recurrent fiscal balance regime changes in Greece. The

We are now in a position to consider the institutions' decision rule properties. The response to the stochastic fiscal balance dynamics is a decision taken under uncertainty. As already noted, the regime is a hidden state variable, so the institutions face a signal extraction problem. A key aspect of the model is that foreign loan commitments are offered in return for (expected) credible fiscal and structural policies. Correspondingly, for the institutions, an awkward question arises in terms of how to calculate the likelihood that the Greek government will implement sustainable macroeconomic policies and play by the rules of engagement of the euro area. To formalize the notion of sustainable fiscal policy under regime switching, we assume that the institutions use  $b_\tau$  in equation (3) as a yardstick to measure the expected soundness of Greece's fiscal policy. To compute the decision rule,  $b_\tau$ , we need the values of  $v = -\int_{s=t}^{\tau} \delta_s e^{-(r_b - \pi - \eta_y)(s-t)} ds$ , which may take two distinct values:  $v^0$  or  $v^1$ . The outcome  $v^0$  represents the case that the Greek government conducts a responsible and sustainable fiscal policy, while the outcome  $v^1$  represents the case that the Greek government reneges on its sound macroeconomic policy commitment. To obtain the analytical values of  $v^0$  and  $v^1$ , we first need to obtain the corresponding Bellman equations for states "0" and "1" respectively:

$$(7) \quad (r_b - \pi - \eta_y)v^0 = -\delta^0 + p_{01}(v^1 - v^0) + \frac{\partial v^0}{\partial t},$$

$$(8) \quad (r_b - \pi - \eta_y)v^1 = -\delta^1 + p_{10}(v^0 - v^1) + \frac{\partial v^1}{\partial t}.$$

It is a straightforward matter to verify that the solution to  $(v^1 - v^0)$  has a corresponding discount rate of  $(r_b - \pi - \eta_y + p_{01} + p_{10})$ . As shown in Appendix B, solving  $v^0$  and  $v^1$  yields,

$$(9) \quad v^0 = \left( -\frac{\delta^0}{\rho} + \frac{p_{01}(\delta^0 - \delta^1)}{\rho(p_{01} + p_{10})} \right) (1 - e^{-\rho(\tau-t)}) \\ - \frac{p_{01}(\delta^0 - \delta^1)}{(p_{01} + p_{10})(\rho + p_{01} + p_{10})} (1 - e^{-(\rho+p_{01}+p_{10})(\tau-t)}),$$

and

$$(10) \quad v^1 = \left( -\frac{\delta^1}{\rho} - \frac{p_{10}(\delta^0 - \delta^1)}{\rho(p_{01} + p_{10})} \right) (1 - e^{-\rho(\tau-t)}) \\ + \frac{p_{10}(\delta^0 - \delta^1)}{(p_{01} + p_{10})(\rho + p_{01} + p_{10})} (1 - e^{-(\rho+p_{01}+p_{10})(\tau-t)}),$$

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two regimes correspond roughly to periods in which most observers believe that fiscal policy actually differed. In any case, the data belie the fragility of the fiscal stance and provide useful clues in terms of where to look for potential model components.



where  $\rho = r_b - \pi - \eta_y$ . Note that equations (9) and (10) satisfy the boundary conditions. Allowing  $\tau \rightarrow t$ , the difference  $b_T e^{-\rho(\tau-t)} - b_t$  approaches zero. Assuming a finite time horizon, we next replace (9) and (10) with their second-order Taylor series expansions. It can then easily be verified that we have:

$$(11) \quad v^0 = -\delta^0 \left( (T-t) - \frac{1}{2} \rho (\tau-t)^2 \right) + \frac{1}{2} p_{01} (\delta^0 - \delta^1) (\tau-t)^2$$

and

$$(12) \quad v^1 = -\delta^1 \left( (T-t) - \frac{1}{2} \rho (\tau-t)^2 \right) - \frac{1}{2} p_{10} (\delta^0 - \delta^1) (\tau-t)^2.$$

From equations (11) and (12), we can see that the institutions incorporate the possibility of switching to different fiscal regimes when forming expectations. They observe the current fiscal regime and make a probabilistic inference regarding future fiscal regimes based on the Markov chain regime-switching process governing the government budget surplus/deficit. An inferred regime change that is expected to be in place for a relatively long time generates a stronger response than one expected to revert after a short duration. In line with this intuition, sustainable fiscal policy is a positive function of  $p_{10}$  and a negative function of  $p_{01}$ . Given the analytical solutions for  $v^0$  and  $v^1$ , we can then finally obtain the analytical solutions for the institutions' decision rule. Substituting equations (9) and (10) into equation (3) yields:

$$(13) \quad b_t^0 = e^{(r_b - \pi - \eta_y)(\tau-t)} \left( b_t + \left( -\frac{\delta^0}{\rho} + \frac{p_{01}(\delta^0 - \delta^1)}{\rho(p_{01} + p_{10})} \right) (1 - e^{-\rho(\tau-t)}) \right. \\ \left. - \frac{p_{01}(\delta^0 - \delta^1)}{(p_{01} + p_{10})(\rho + p_{01} + p_{10})} (1 - e^{-(\rho+p_{01}+p_{10})(\tau-t)}) \right)$$

and

$$(14) \quad b_t^1 = e^{(r_b - \pi - \eta_y)(\tau-t)} \left( b_t + \left( -\frac{\delta^1}{\rho} - \frac{p_{10}(\delta^0 - \delta^1)}{\rho(p_{01} + p_{10})} \right) (1 - e^{-\rho(\tau-t)}) \right. \\ \left. + \frac{p_{10}(\delta^0 - \delta^1)}{(p_{01} + p_{10})(\rho + p_{01} + p_{10})} (1 - e^{-(\rho+p_{01}+p_{10})(\tau-t)}) \right).$$

Next, we characterize money demand.<sup>12</sup> Suppose that money demand is given by

$$(15) \quad m_s - p_s = \alpha_0 - \alpha_1 \ln r_s,$$

where  $m_t$ ,  $p_t$  and  $r_t$  denote money demand, the price level and the nominal interest rate respectively;  $s$  denotes the financial assistance period  $s \in (t, \tau)$ . All variables, except the interest rate, are in logarithmic form and the parameter  $\alpha_1$  is positive. For simplicity, we exclude income from the money demand function. In turn and without loss of generality, the money supply is made up of domestic credit and intergovernmental financial support from euro area member states and the IMF to cope with the financial difficulties and economic challenges since May 2010:

$$(16) \quad m_s = c_s + f_s,$$

where  $c_s = \ln C_s$  is domestic credit in logarithmic terms and  $f_s = \ln F_s$  is the financial assistance provided to Greece under the 1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> adjustment programmes in logarithmic terms. We assume that the money market clears. To focus the analysis on the effects of changes in the fiscal policy process, domestic credit takes the following form:

$$(17) \quad C_s = \beta_0 + \beta_1 B_s,$$

where  $B$  is the public debt level and the parameters  $\beta_0$  and  $\beta_1$  are positive.

Furthermore, we assume that purchasing power parity holds.

$$(18) \quad \ln P_s = \ln S_s - \ln P_s^*,$$

where  $P_s$ ,  $P_s^*$  and  $S_s$  are the domestic price level, the foreign price level and the exchange rate, respectively. An asterisk always denotes foreign variables. Finally, uncovered interest rate parity implies:

$$(19) \quad r_s = r_s^* + \frac{d \ln S_s}{ds},$$

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<sup>12</sup> The following assumptions stem from the currency crisis literature. The models in this literature start with the seminal continuous-time, perfect foresight model developed by Krugman (1979). Masson (2007, pp. 3 - 60) provides a thorough review of the currency crisis literature. Note that the paper isn't really a currency crisis paper. Contrary to the first generation crisis approach no speculative attack occurs which forces a transition to a floating rate prior to the depletion of the reserves. What the current paper does have in common with first generation approaches is the use of a monetary model and the modeling of money growth in the post-crisis regime as a function of debt monetization. For recent contributions to the "sudden stop" literature, see Montiel (2013, 2014) and Sula (2010).

where  $\ln S_t$ , and  $r_s$  and  $r_s^*$  are the domestic and foreign interest rates respectively. Within the single currency area,  $S_t$  is normalised to 1. Once Greece leaves the euro area, the exchange rates is assumed to float freely.

To gain further insights into the properties of the model, the next step is to determine the degree of depreciation of the relaunched drachma after a Grexit. Assuming that the Greek government is determined to carry things to the extreme, the institutions finally deliver the bitter truth to the Greek government. In other words, we consider the situation in which fiscal irresponsibility and lack of willingness to undertake reform turn bad, leading to a withdrawal from the euro area. This happens when room for manoeuvre has run out and the institutions deem  $b_t^1 > b_t$  to be too high and unsustainable.

The level of the drachma exchange rate depends critically on what kind of exchange rate regime is expected to prevail right after the Grexit. Without a foreign line of credit, it is probably reasonable to consider a free-floating drachma as representing the alternative to euro area membership. Furthermore, we assume that Greece remains vulnerable to political upheaval in such an explosive situation, putting the country on a knife edge. To this end, we assume that during a tranquil period, the macroeconomic environment is still characterized by the Markov switching framework presented above. This does not preclude a change in model parameters, analysed in the numerical model analysis below. Finally, we assume that Greece will leave the euro area permanently.<sup>13</sup> These assumptions can clearly be stated to imply:

$$(20) \quad \frac{db_s}{ds} = \left( -\delta^1 - \frac{p_{10}(\delta^0 - \delta^1)}{r_s - \pi - \eta_y + p_{01} + p_{10}} \right) + (r_b - \pi - \eta_y)b_s$$

after the Grexit as  $\tau$  approaches infinity. Note that, unlike in the model presented above, the lower interest rate  $r_b$  no longer applies. To derive the associated rate of change for nominal public debt, we first need to substitute  $-\delta_s = -\delta^1 - \frac{p_{10}(\delta^0 - \delta^1)}{r_s - \pi - \eta_y + p_{01} + p_{10}}$  into equation (1). Simplifying further then allows us to obtain:

$$(21) \quad \frac{dB_s}{ds} = y_s P_s \left( -\delta^1 - \frac{p_{10}(\delta^0 - \delta^1)}{r_s - \pi - \eta_y + p_{01} + p_{10}} \right) + r_s B_s$$

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<sup>13</sup> In the course of the debate, a temporary Grexit has also been suggested. If the ECB allowed the Greek authorities to introduce an emergency parallel “currency”, Greece might in effect suspend its euro area membership without technically leaving. This could then be reversed if Greece struck a deal with its creditors at a later date. By continuing as part of the euro area, the Bank of Greece might retain credibility, which it would otherwise lack. The positive impact would be that the Greek economy might not slump as far as it would otherwise and the drachma might depreciate less than otherwise. Technically, this can also be modelled by the Markov switching approach.

We can now employ equations (17) and (1) to get the expected paths for credit growth:

$$(22) \quad \frac{1}{C_s} \frac{dC_s}{ds} = \frac{\beta_1}{\beta_0 + \beta_1 B_s} \left[ y_s P_s \left( -\delta^1 - \frac{p_{10}(\delta^0 - \delta^1)}{r_s - \pi - \eta_y + p_{01} + p_{10}} \right) + r_s B_s \right].$$

As a by-product of the modelling exercise, we next back out the exchange rate of the relaunched drachma after a Grexit as a function of the other parameters of the model. The floating exchange rate implies that PPP holds. This gives us:

$$(23) \quad \frac{d \ln S_s}{ds} = \frac{dc_s}{ds} = \frac{1}{C_s} \frac{dC_s}{ds},$$

where foreign prices are constant over time and domestic inflation is equal to domestic credit growth. Recall that the instantaneous rate of depreciation of the relaunched drachma after the Grexit is determined by  $r_s = r_s^* + \frac{d \ln S_t}{ds}$ . As shown in Appendix C, the drachma exchange rate after the Grexit is given by:

$$(24) \quad \ln S_s = \alpha_1 \ln \left( 1 + \frac{\frac{\beta_1}{\beta_0 + \beta_1 B_s} \left[ y_s P_s \left( -\delta^1 - \frac{p_{10}(\delta^0 - \delta^1)}{r_s - \pi - \eta_y + p_{01} + p_{10}} \right) + r_s B_s \right]}{r_s^*} \right)$$

Equation (24) is based upon the assumption of a constant money supply. Intuitively, equation (24) implies that a decrease in  $p_{10}$  – and thus more a long-lasting unsustainable trajectory of macroeconomic policies – will, *ceteris paribus*, lead to higher depreciation of the new drachma.

In this section we have built a basic model – a road map of reality, if you will – to enhance our understanding of the three-act Greek tragedy. Armed with this framework, we now turn to numerical model simulations and robustness checks.

### 3. Model Simulations and Sensitivity Analysis

Using the model as in a laboratory test, we now aim to provide a quantitative assessment of the modelling framework. Furthermore, controlled experiments can be conducted to investigate hypothetical questions. For example, how would the creditor’s decision rule differ for different regime-switching probabilities? Similar exercises are implemented to simulate the impacts of various other parameter changes. This uncovers the sensitivity of the benchmark results with respect to several key parameters. The obvious next question is what are the “correct” values of the parameters? As a general rule, we have chosen parameters consistent with the macroeconomic and finance literature.

Some of the parameters are based on the estimates of several authors. Other parameters are more subjective and readers may disagree with the numbers and consider them speculative. As this is the case, we have calculated the numerical solutions for ranges of parameter values and have thereby determined which parameters are particularly critical.

The unit time length corresponds to one year. To assess the impacts of different probabilities regimes on the values of  $b_t^0$  and  $b_t^1$  accurately, we need to assign some benchmark values for equations (13) and (14). The interest rate  $r_b$  is assumed to be 2.0 per cent. This is broadly consistent with the actual figure. The GDP growth rate and the inflation rate are 1.0 per cent and zero per cent respectively. The current debt-to-real income level  $b_t$  is equal to 1.8. A 1.0 per cent GDP growth rate is consistent with recent long-term forecasts (see McQuinn and Whelan, 2015). According to the IMF (2015a, 2015b, 2015c), the revised GDP growth assessment for Greece is 1.5 per cent, although it describes this forecast as “ambitious”. The creditor’s time horizon ( $\tau - t$ ) is assumed to be 15 years.<sup>14</sup> Next, we need to focus attention on the fiscal balance and Markov switching benchmark values. In accordance with the demands of the institutions, the fiscal surplus in terms of GDP in state “0” is assumed to be  $\delta^0 = 0.035$ . The fiscal deficit in state “1” is assumed to be  $\delta^1 = -0.020$ . The baseline benchmark probabilities  $p_{01}$  and  $p_{10}$  are both equal to 0.2. The expected macroeconomic policy regime duration implied by the baseline calibration is thus  $[1/(1 - p_{01})] = [1/(1 - p_{10})] = [1/(1 - 0.2)] = 1.25$  years. Below, we provide results for several additional specifications around these central values, intended to probe the robustness of our calibrations and to verify the validity of our conclusions.

Does the model mimic outcomes that broadly match those witnessed in Greece since the country ran into difficulties and was placed under the financial market’s spotlight in 2010?<sup>15</sup> First, we consider alternative specifications of the transition matrix  $P$ . Logic implies that the numerical results are expected to be sensitive to the parameters of matrix  $P$ . Note that the standard fixed-regime model without macroeconomic policy uncertainty is nested within our framework. By deriving  $p_{01} \rightarrow 0$  or  $p_{10} \rightarrow 0$ , our regime-switching model with future policy uncertainty collapses into a fixed-regime model without future policy uncertainty. Put together Greece’s government paralysis and creditors’ fear of instability and what emerges?

The three-dimensional graphs map the  $b_t$ -planes for both states ( $i = 0,1$ ) and alternative calibrations of the transition matrix in the range  $p_{01} \in (0,0.4)$  and  $p_{10} \in (0,0.4)$  respectively. In addition, the various model simulations in the three rows of the graph trace the decision rule equation (3) for

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<sup>14</sup> The average maturity of the Greek sovereign debt is approximately 16 years (De Grauwe, 2015). This is considerably longer than the maturities of the government debt of the other euro area countries.

<sup>15</sup> The numerical results should be viewed as largely illustrative. Applying the modelling framework in practice yields an intuitive interpretation of the model without requiring a background in stochastic calculus to understand the arguments in the text.

different combinations of the government budget surplus/deficit across regimes. Remember that the expected  $b_\tau$  serves as the basis for the decision making of the institutions.<sup>16</sup>

As can be seen,  $b_\tau^1$  always exceeds  $b_\tau^0$  for a given constellation of parameters. Furthermore, Figure 1 clearly reveals that the regime-switching probabilities  $p_{01}$  and  $p_{10}$  are very important in explaining  $b_\tau^0$  and  $b_\tau^1$ . In other words,  $p_{01}$  and  $p_{10}$  have a prominent effect on the creditors' decision rule. Moreover, the signs are intuitive: in response to higher  $p_{01}$  ( $p_{10}$ ),  $b_\tau$  increases (decreases) and thus the Grexit is more (less) likely. A politically fragile situation characterized by high  $p_{01}$  in combination with small  $p_{10}$  reduces confidence sharply and trust between the Greek government and the institutions may break down almost entirely. How are the numerical results to be interpreted in terms of the debate among the institutions? According to the IMF (2015a, 2015b), Greece's debt-to-GDP ratio will peak in 2016, but will still be 175 per cent in 2020 and 160 per cent in 2022. The IMF views a debt-to-GDP ratio above 120 per cent unsustainable. For plausible jump probabilities, the results thus confirm the IMF's (2015a, 2015b) view that Greece's debt remains unsustainable and will continue to be so unless watering down of the fiscal targets imposed by the institutions provides breathing space for Greece. Thus, Greece's tightrope walk, which may bring the country to the edge, is likely to continue. Consequently, Greece's European partners may have to provide significant debt relief in the future, well beyond what has been considered so far.<sup>17</sup> The flipside of the argument is that staying afloat in the euro area without a further bailout requires the combination of a very small  $p_{01}$  in combination with a sufficiently large  $p_{10}$ .<sup>18</sup>

Overall, we interpret the results in Figure 1 as suggesting that macroeconomic policy uncertainty and political upheaval might be playing a sizeable role in the currency crisis and certainly a more important one than typically presumed in modern international economics. In other words, our modelling approach has the appealing virtue of conveying important and useful information about the three-act Greek tragedy while sidestepping the contentious issue of an appropriate political economy microfoundation.

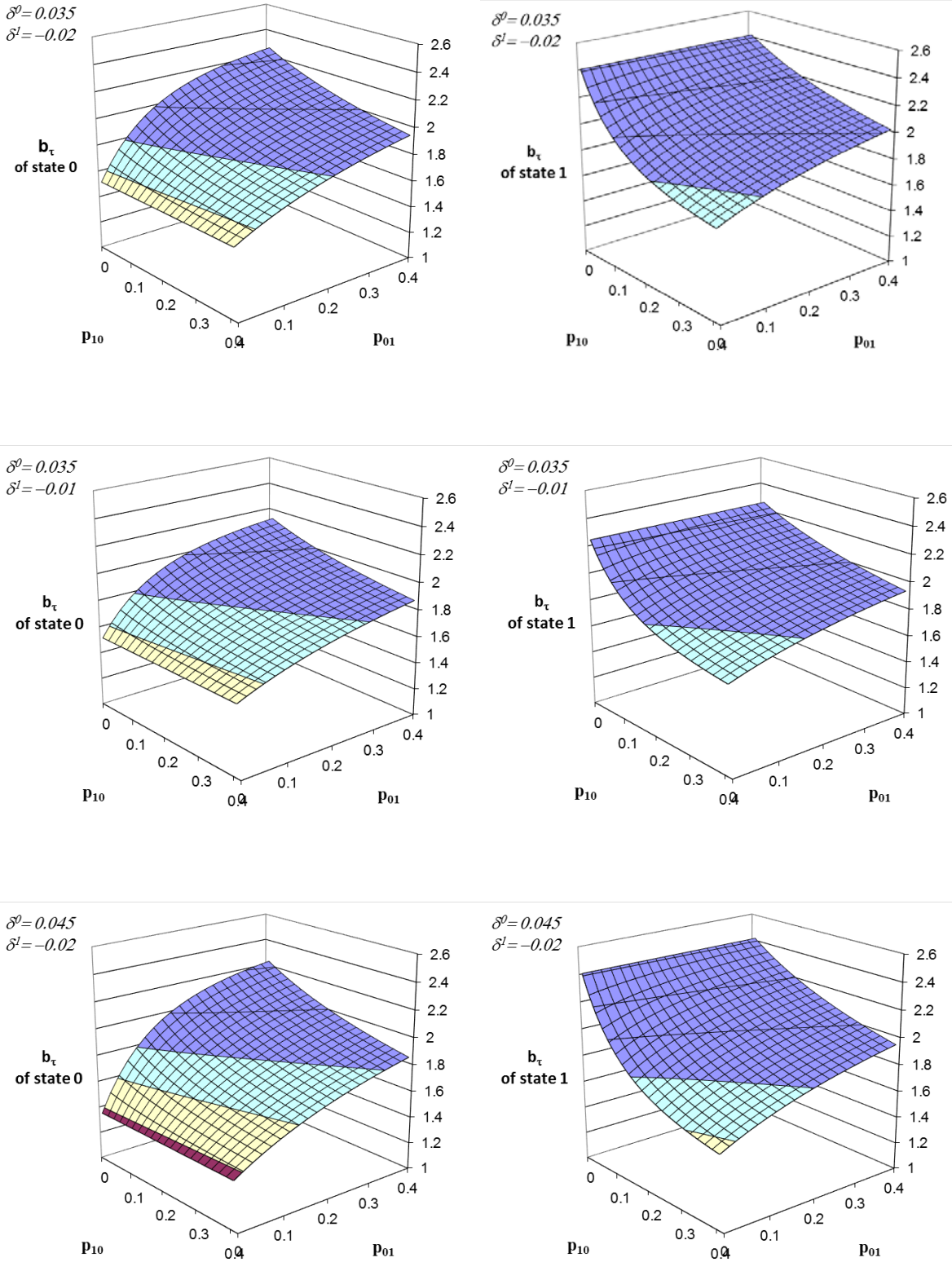
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<sup>16</sup> We use the term "creditors' decision rule" as it better captures the economic concept than the more technical counterpart  $b_\tau$ , i.e. our specific measure. This also has the virtue of easing exposition and avoiding ambiguity.

<sup>17</sup> In 2016, the institutions will resume their talks with Greece concerning another debt restructuring, with the main objective of ensuring that Greece does not face unstable dynamics. Note that default on sovereign debt is rarely full and absolute. Generally, payments are suspended and restructuring takes place. This process typically involves both a reduction in total commitments and a rescheduling of payments. Reinhart and Trebesch (2015) have shown that since its independence in 1829, Greece has defaulted four times on its external creditors. In other words, bailouts are a recurrent theme in Greek history.

<sup>18</sup> There is no cast iron rule for what debt ratio is too high, but there is no question that where Greece is heading with large (small)  $p_{01}$  ( $p_{10}$ ) will not be sustainable in the medium to long term.

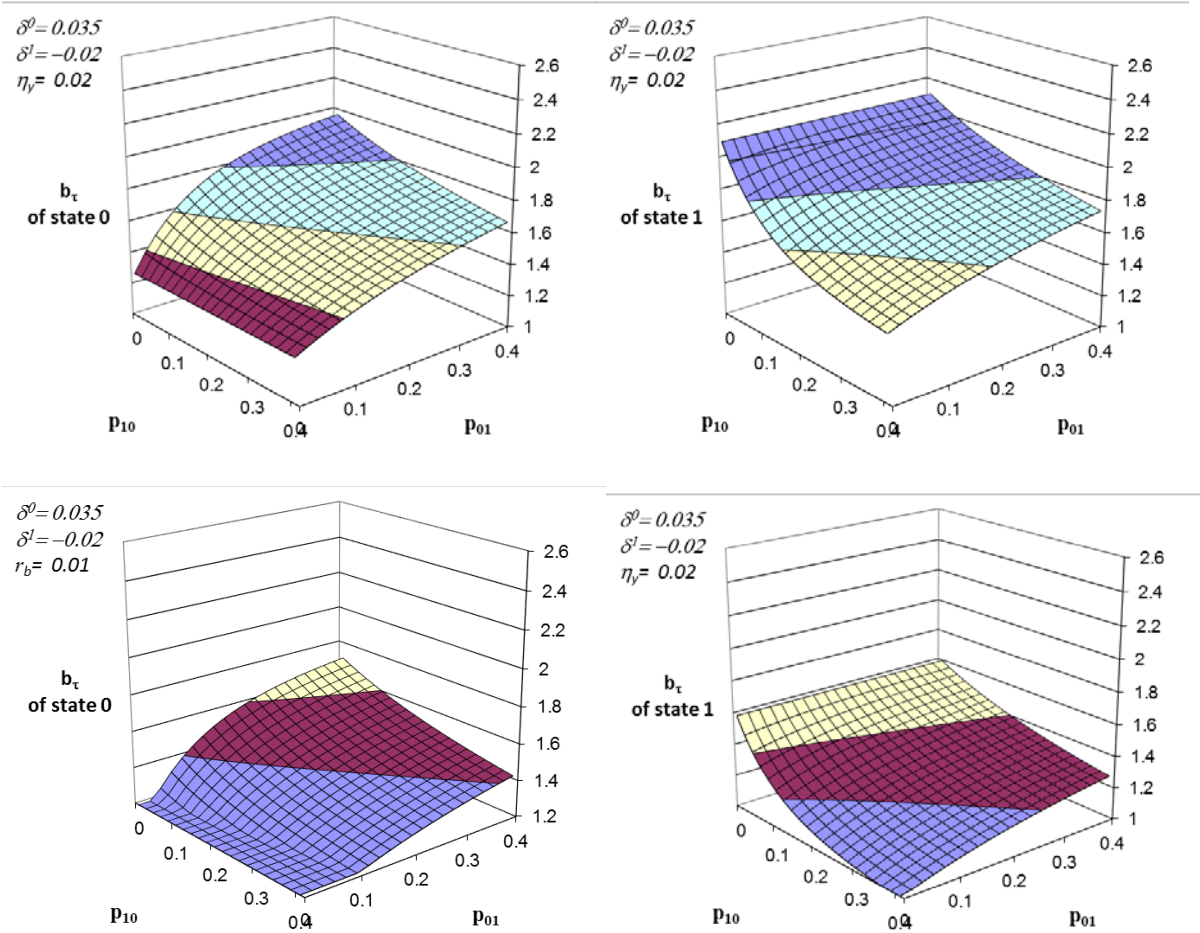
**Figure 1: Creditors' Decision Rule under Alternative Calibrations of the Transition Matrix  $P$**



Notes: The value ranges are defined as follows. Dark blue:  $b_\tau > 1.8$ ; light blue:  $1.6 < b_\tau < 1.8$ ; yellow:  $1.4 < b_\tau < 1.6$ ; red:  $1.2 < b_\tau < 1.4$ .

Next, we analyse the implications of alternative GDP growth rates  $\eta_y$ . Alongside structural reforms, the GDP growth rate may change. Higher (lower) tax revenues in the years ahead may stem from accelerated (delayed) structural reforms and good (bad) governance. To see how the GDP growth rates  $\eta_y = 0.02$  vs.  $\eta_y = 0.03$  affect the creditors' decision rule, let us consider Figure 2. The higher GDP growth rates represent the optimistic case, in which the curtailing and streamlining of public expenditures, incorporating the informal economy into the formal one, increasing the size of the tax base and attacking the clientelist system in which rent-seeking groups are bought off with subsidies and tax breaks, leads to higher GDP growth than in the baseline scenario.

**Figure 2: The Impact of Alternative Growth Rates  $\eta_y$  under Alternative Calibrations of the Transition Matrix  $P$**



**Notes:** The value ranges are defined as follows. Dark blue:  $b_\tau > 1.8$ ; light blue:  $1.6 < b_\tau < 1.8$ ; yellow:  $1.4 < b_\tau < 1.6$ ; red:  $1.2 < b_\tau < 1.4$ ; dark blue:  $1.2 < b_\tau < 1.0$ .



Again, the three-dimensional graphs make it possible to determine the impact of attenuated and elevated political uncertainty respectively. The main conclusions to be drawn are as follows. First, the eye-catching difference between panel A in Figure 1 and Figure 2 is consistent with the central message of this paper. Broadly speaking, more (less) policy uncertainty shifts the  $b_\tau$ -plane up (down). In other words, the costs associated with an erratic and dysfunctional political environment are again clearly visible. Second, higher GDP growth makes Greece's public debt much more sustainable. However, an upshot of the numerical results is that generating higher growth is a tall order.<sup>19</sup> In the positive scenario,  $\eta_y = 0.03$ , the Greek economy will benefit from growth-enhancing reforms and dynamic global growth and will manage to hit its austerity targets. How realistic are higher GDP growth rates in the years ahead? The optimistic view is that vigorous supply-side reforms have a good chance of stabilizing the economy and achieving higher GDP growth rates. However, the contention that Greece would achieve faster growth after a Grexit runs into two counterarguments. First, a Grexit will involve a long, uncertain and economically costly transition process, transforming the Greek economy, reducing its GDP, increasing the volatility of GDP and weakening the financial system in the first instance. Second, given Greece's fiscal mismanagement and anti-market and anti-enterprise policies in the past, it remains uncertain whether the Greek government really wishes to address the disease and whether it can restore confidence. These are not extreme or unrealistic scenarios. After watching successive Greek governments of all political stripes falling short on the reform agenda as the country has lurched from one crisis to the next, the pessimistic scenario seems entirely realistic. In fact, one can argue that the lack of readiness of the Greece authorities to embrace structural reforms is a drag on further growth. This is also a channel through which Grexit vulnerability becomes compounded over time. Ultimately, the institutions may abandon the defence of Greece's euro area membership.

So far, we have assessed the implications of changes in the perceived transition probabilities. Next, we analyse the implications of alternative interest rates  $r_b$  and thus interest rate concessions of different degrees. In the literature, conflicting findings and views on debt refinancing rates and the sustainability of Greek debt have been expressed. For instance, De Grauwe (2015), with an assumption of modest growth, finds public debt sustainable, whereas the IMF (2015a, 2015b) finds that the debt cannot be considered sustainable (for a comparison, see Consiglio and Zenios [2015]).

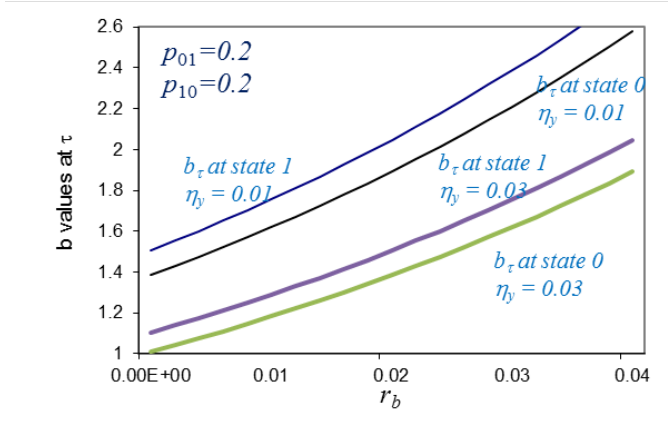
Due to the generous interest subsidies contained in the rescue packages, the average interest rate in the Greek budget is currently only around 2 per cent. As large parts of Greek government debt will remain subject to favourable conditions for some time, thanks to the assistance programmes, this average interest rate is unlikely to change to any considerable degree over the next few years. As Greece

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<sup>19</sup> For a recent DSGE analysis of the costs and benefits of delaying austerity in Greece, see House and Tesar (2015). In this analysis, the authors assume the full credibility of the Greek government with regard to future reforms. In other words, policy uncertainty has been suppressed in the analysis. Cacciatore et al. (2015) have recently explored the consequences of labour and product market reforms within monetary union in a DSGE setup.

gradually makes a comeback on the capital market, however, average interest rates look set to chart a moderate increase in the medium term. In 2025, for example, around one third of Greek government debt is likely to be linked again directly to the country’s credit rating. This, combined with a general increase in yields, will push the average interest rate in the Greek budget up to around 3.0–3.5 per cent in 2025.

**Figure 3: Creditors’ Decision Rule under Alternative  $r_b$  and  $\eta_y$**



The implications of alternative interest rates  $r_b$  can be understood from Figure 3. So, how to interpret the results? First, in line with intuition and the conventional view, we find that the interest rate is very important for Greece’s debt sustainability and interest rate concessions consistently free up fiscal space that can be used to service public debt. Second, the purple and green lines map the simulated impact of alternative interest rates  $r_b$  upon the institutions’ decision rule for a higher GDP growth rate of  $\eta_y = 0.03$ . This represents the optimistic scenario, namely that structural reforms in Greece are implemented and achieve growth. The comparison of the various trajectories indicates that higher GDP growth rates are of the utmost importance in making the existing debt levels sustainable. Third, such brighter spots aside, all interest rate above  $r_b \approx 0.025$  imply that Greece is not only illiquid but insolvent. In other words, interest rates  $r_B$  above 0.025 will raise warning flags and undermine euro area membership and may trigger a Grexit. Finally, compared to the literature, the simulated pathways are slightly more optimistic than the predictions of the IMF (2015a, 2015b, 2015c), but more pessimistic than those of De Grauwe (2015).

Finally, we consider the implications of a Grexit for the relaunched drachma.<sup>20</sup> In other words, the Greek government is assumed to continue blindly on the path of pursuing unsustainable policies so

<sup>20</sup> After exit, Greece would have to negotiate continued EU participation. The EU treaties have a provision for leaving the union, but not just the eurozone. That negotiation would be all the more difficult were new authorities in Greece to default on debt to the European Financial Stability Facility, the ECB and the IMF. Furthermore, Greek firms would face legal and financial disaster. Some contracts governed by Greek law would be converted into a new drachma, while other foreign law contracts would remain in euros. Many contracts could end up in legal disputes over whether they should be converted or not.

that the creditors finally lose patience. Again, the numerical simulations are performed with regard to a benchmark case. Where possible, parameter values are drawn from empirical studies. We set the central benchmark parameters as follows. The interest rate elasticity of money demand in equation (15) is set at  $\alpha_1 = 0.3$ , as in Mohsen and Economidou (2005).<sup>21</sup> The foreign interest rate is set to  $r^* = 0.03$ . For simplicity, we have normalized  $y_s = 1$  and  $P_s = 1$ . Some other parameters are inherently difficult to measure. For a start, the interest and inflation rates right after the Grexit are assumed to be  $r_t = 0.18$  and  $\pi = 0.16$  respectively. Finally, we assume  $B_s = 1.8$ ,  $\beta_0 = 1$  and  $\beta_1 = 0.6$ . Again we consider an uncertain policy environment. A key aspect of the Markov switching modelling framework is that Grexit is a process, not an event. Even if negotiations fail, even if Greece defaults, even if the Greek authorities start to issue new drachma – even then, an erratic macroeconomic environment matters in policy choices and outcomes.

**Figure 4: Depreciation of the New Drachma after a Grexit**

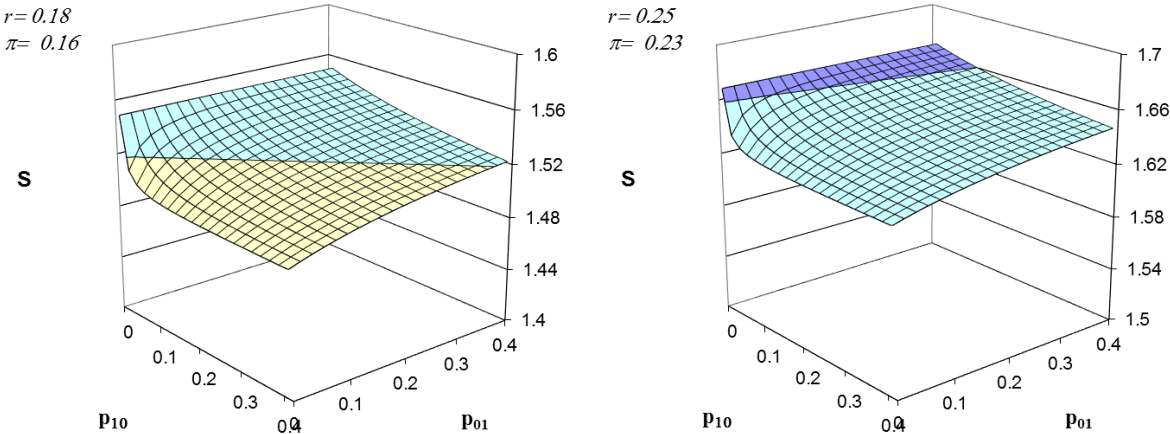


Figure 4 shows that after the Grexit, the new drachma exchange will take a nosedive. Our theory-consistent baseline estimate in the left-hand panel of Figure 4 suggests a depreciation of the new drachma vis-à-vis the euro of around 50 per cent, but it could be much worse in the short term.<sup>22</sup> Comparing our results to those of the IMF (2012, Box 2, p. 46), it is comforting that the results for the drachma exchange rate are remarkably similar despite the differences in the models. What explains the new drachma halving in value? In other words, what does our intuition tell us about the above result? It is worth briefly summarizing the transmission channels and feedback loops from depreciation to

<sup>21</sup> In Mohsen and Economidou (2005, Table 3) interest rate semi-elasticities for Greece are presented. The way to interpret the coefficients in the log-linear specification is as the percentage change in  $(m_t - p_t)$  that we obtain from one unit change in  $r_t$ . This is in contrast to the log-log specification in equation (15), in which  $\alpha_1$  gives the percentage change in  $(m_t - p_t)$  which we obtain from a percentage change in  $r_t$ . Therefore, one has to convert the semi-elasticity to full elasticity.

<sup>22</sup> During exchange rate turmoil, financial markets may revise the perceived probability of realignment upwards and may even anticipate an overshooting of the exchange rate after a collapse.

growth and inflation. On the one hand, Greece would enter another deep recession, which would push unemployment up further and reduce budget revenues, necessitating another round of harsh fiscal consolidation. On the other hand, due to structural factors, the responsiveness of the economy to price changes is rather low: Greece ranks below most other euro area countries in terms of the share of foreign trade to GDP and the elasticity of exports to international price competitiveness. Consequently, the depreciation of the new drachma may not revive the Greek economy to any great extent. In the right-hand panel of Figure 4, we illustrate graphically how sensitive the depreciation of the new drachma is to different levels of inflation and interest rates after the Grexit. To summarize, when Greece is heading for runaway inflation with  $r_t = 0.25$  and  $\pi = 0.23$ , the depreciation of the new drachma is even more pronounced.<sup>23</sup>

#### 4. Conclusion and Future Research

Our admittedly simplistic model provides a novel analysis of the three-act Greek tragedy and sheds light on key mechanisms which could lead to a Grexit. The framework was deliberately kept simple and is about basic issues: public debt, sovereign default and euro area loans. More precisely, we discuss the developments in Greece since 2010 within a set up in which a Markov regime-switching process is embedded in a standard first-generation currency crisis framework. In other words, the modelling setup is a “hybrid” approach. It uses the Markov switching framework to model the merry-go-round of Greek policymakers and combines it with the financial assistance programmes. We should add at this point that we would like to be cautious in claiming that our empirically-motivated Markov switching framework corresponds to causal effects of exogenous switches on endogenous economic outcomes. Nevertheless, we believe that our modelling approach is informative regarding the propagation of these shocks shaking the euro area. As far as we are aware, ours is the first approach to address this topical question.

Although the canonical model presented above does not pretend to be comprehensive, it distils the most important impact channels and therefore has some important virtues. First of all, the currency crises clearly reflect a basic inconsistency between domestic fiscal policy and currency union; the specific, highly simplified form of that discrepancy in the set-up may be viewed as a metaphor for the more complex policy incoherence in Europe. Second, although the euro area leaders reached an agreement with Greece in August 2015, it remains uncertain whether the 3<sup>rd</sup> assistance package and the required market-oriented reforms will generate lasting growth. Of course there is the risk that the bailouts may buy time but also make it easier to waste it. This may store up bigger problems further

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<sup>23</sup> A similar robustness analysis can be conducted for other model parameters but leads to no substantial additional insights.

down the road. Ultimately, this depends upon whether the Greek authorities will have the strength and commitment needed to implement the necessary reform path over the coming years.<sup>24</sup>

We recognize that the model presented, with stochastic changes in the policy stance, referred to as regime shifts, can be seen as an overly simplistic set-up. In particular, a downside of the reduced-form approach is that it assumes that switching is exogenous. The disadvantage of this approach is that policymakers are locked in to a given credibility level. Nevertheless, we hope that this paper will stimulate further research in models with more detailed behavioural structure. There are several dimensions we have not considered in our modelling framework. Going forward, one possible extension would be to add a political economy foundation, permitting discussion of the implementation of growth-enhancing structural reforms in politically fragile countries. This is clearly an area that deserves further study.

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<sup>24</sup> The potential gains of structural reforms depend critically on the interaction between several policy areas, such as competition in product markets, streamlined labour law, the efficiency of public administration and the ease of doing business, to name but a few. In other words, jointly implemented reforms tailored to national conditions are needed to obtain sizeable growth effects.

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## Appendix A: Regime Switching in Greece's Budget Surplus/Deficit to GDP Ratio

A two-regime Markov switching model, allowing for regime switching in coefficients and variances, is confronted with quarterly Greek data for the government budget surplus/deficit-to-GDP ratio  $\delta_t$  from 2006. The model takes the following form:

$$(A1) \quad -\delta_t = \alpha_0 + \alpha_1 s_t + u_t$$

$$(A2) \quad u_t = \phi_1 u_{t-1} + \phi_2 u_{t-2} + \dots + \phi_r u_{t-r} + \varepsilon_t$$

$$(A3) \quad \varepsilon_t \sim N(0, \sigma_0^2 + \sigma_1^2 s_t)$$

where  $s_t = \{0,1\}$ ,  $\alpha_0$ , and  $\sigma_0^2$  are the mean and variance in state  $s_t = 0$  and the parameters  $\alpha_0 + \alpha_1 s_t$  and  $\sigma_0^2 + \sigma_1^2 s_t$  are the mean and variance in state  $s_t = 1$ , respectively. The lags in equation (A2) are estimated ex post, i.e.  $r$  has no effect on the Markov switching estimates.

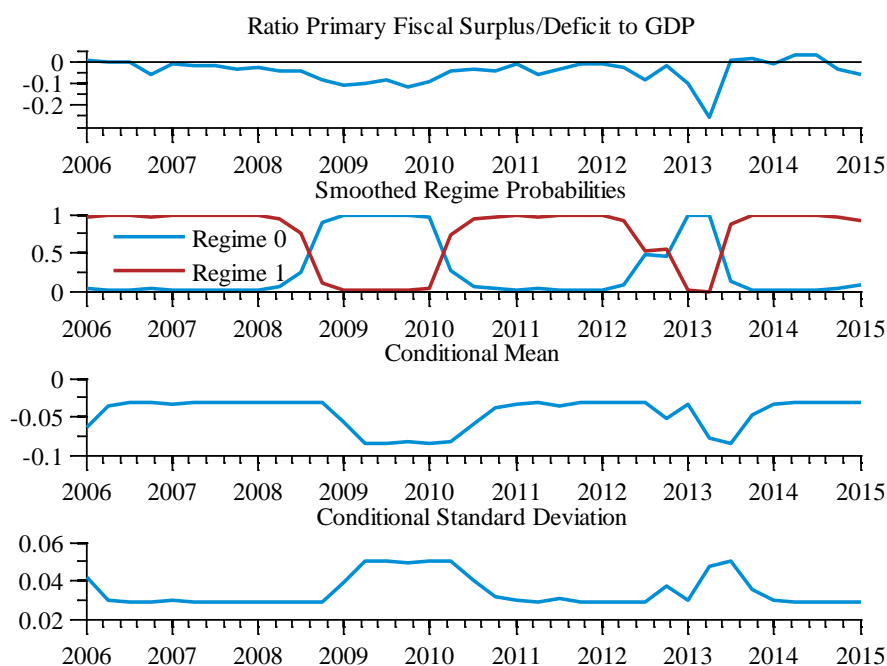
### Maximum Likelihood Parameter Estimates and Standard Errors

Parameter	Estimate	Standard error	p-value
$\alpha_0$	-0.1030	0.0322	0.00
$\alpha_1$	0.0226	0.0063	0.00
$\sigma_0^2$	0.003344	0.0016	0.05
$\sigma_1^2$	0.000635	0.0002	0.01
$p_{00}$	0.77	0.13	0.13
$p_{11}$	0.91	0.26	0.00

Notes: The model is estimated in absolute values, i.e. 0.01 = 1%. The expected duration of regime "0" ("1") is 4.29 (11.17) quarters. Data Source: ECB Statistical Data Warehouse.

Delving into the regression output reveals the presence of two regimes, one characterized by low and the other by high the government budget surplus/deficit. Smoothed probabilities are estimated using the entire sample.

### Model Estimates





## Appendix B: Derivation of the Solutions for $v^0$ and $v^1$

Subtracting equation (8) from (7) gives us:

$$(B1) \quad (r_b - \pi - \eta_y + p + p_{10})(v^1 - v^0) = \delta^0 - \delta^1 + \frac{\partial(v^1 - v^0)}{\partial t}.$$

It can clearly be seen that the solution to  $v^1 - v^0$  is:

$$(B2) \quad (v^1 - v^0) = \frac{\delta^0 - \delta^1}{r_b - \pi - \eta_y + p_{01} + p_{10}} \left(1 - e^{-(r_b - \pi - \eta_y + p + p_{10})(\tau - t)}\right).$$

Substituting (B2) into equation (7) and equation (8) in the main text yields:

$$(B3) \quad (r_b - \pi - \eta_y)v^0 = -\delta^0 + \frac{p_{01}(\delta^0 - \delta^1)}{r_b - \pi - \eta_y + p_{01} + p_{10}} \left(1 - e^{-(r_b - \pi - \eta_y + p_{01} + p_{10})(\tau - t)}\right) + \frac{\partial v^0}{\partial t},$$

$$(B4) \quad (r_b - \pi - \eta_y)v^1 = -\delta^1 - \frac{p_{10}(\delta^0 - \delta^1)}{r_b - \pi - \eta_y + p_{01} + p_{10}} \left(1 - e^{-(r_b - \pi - \eta_y + p_{01} + p_{10})(\tau - t)}\right) + \frac{\partial v^1}{\partial t}.$$

As equations (B3) and (B4) are no longer coupled, they can be solved separately. To keep the analysis simple, and without loss of generality, we can assume that  $v^0$  has the following solution:

$$(B5) \quad v^0 = \alpha \left(1 - e^{-(r_b - \pi - \eta_y)(\tau - t)}\right) + \beta \left(1 - e^{-(r_b - \pi - \eta_y + p_{01} + p_{10})(\tau - t)}\right).$$

Substituting equation (B5) back into equation (B3) and rearranging leaves us with:

$$(B6) \quad \left[ (r_b - \pi - \eta_y)(\alpha + \beta) + \delta^0 - \frac{p_{01}(\delta^0 - \delta^1)}{r_b - \pi - \eta_y + p_{01} + p_{10}} \right] \\ - \left[ (r_b - \pi - \eta_y)\alpha - (r_b - \pi - \eta_y)\alpha \right] e^{-(r_b - \pi - \eta_y)(\tau - t)} \\ - \left[ (r_b - \pi - \eta_y)\beta - \frac{p_{01}(\delta^0 - \delta^1)}{r_b - \pi - \eta_y + p_{01} + p_{10}} \right] \\ - (r_b - \pi - \eta_y + p_{01} + p_{10})\beta \Big] e^{-(r_b - \pi - \eta_y + p_{01} + p_{10})(\tau - t)} = 0.$$

Equation (B6) holds if all items in parentheses are equal to zero. The second set of parentheses related to  $e^{-(r_b - \pi - \eta_y)(\tau - t)}$  is already equal to zero. From the first and third sets of parentheses, we have:

$$(B7) \quad \beta = -\frac{p_{01}(\delta^0 - \delta^1)}{(p_{01} + p_{10})(r_b - \pi - \eta_y + p_{01} + p_{10})}.$$

and the first set gives us:

$$(B8) \quad \alpha + \beta = -\frac{\delta^0}{(r_b - \pi - \eta_y)} + \frac{p_{01}(\delta^0 - \delta^1)}{(r_b - \pi - \eta_y)(r_b - \pi - \eta_y + p_{01} + p_{10})}.$$

Substituting equation (B7) into equation (B8) yields:

$$(B9) \quad \alpha = -\frac{\delta^0}{(r_b - \pi - \eta_y)} + \frac{p_{01}(\delta^0 - \delta^1)}{(r_b - \pi - \eta_y + p_{01} + p_{10})} \left[ \frac{1}{(r_b - \pi - \eta_y)} + \frac{1}{(p_{01} + p_{10})} \right]$$

$$= -\frac{\delta^0}{(r_b - \pi - \eta_y)} + \frac{p_{01}(\delta^0 - \delta^1)}{(r_b - \pi - \eta_y)(p_{01} + p_{10})}.$$

Therefore, we have the solution for  $v^0$  as follows:

$$(B10) \quad v^0 = \left( -\frac{\delta^0}{(r_b - \pi - \eta_y)} + \frac{p_{01}(\delta^0 - \delta^1)}{(r_b - \pi - \eta_y)(p_{01} + p_{10})} \right) \left( 1 - e^{-(r_b - \pi - \eta_y)(\tau - t)} \right)$$

$$- \frac{p_{01}(\delta^0 - \delta^1)}{(p_{01} + p_{10})(r_b - \pi - \eta_y + p_{01} + p_{10})} \left( 1 - e^{-(r_b - \pi - \eta_y + p_{01} + p_{10})(\tau - t)} \right).$$

The next step is to obtain the corresponding solution for  $v^1$ . Following the same algebra steps as before, yields:

$$(B11) \quad v^1 = \left( -\frac{\delta^1}{(r_b - \pi - \eta_y)} - \frac{p_{10}(\delta^0 - \delta^1)}{(r_b - \pi - \eta_y)(p_{01} + p_{10})} \right) \left( 1 - e^{-(r_b - \pi - \eta_y)(\tau - t)} \right)$$

$$+ \frac{p_{10}(\delta^0 - \delta^1)}{(p_{01} + p_{10})(r_b - \pi - \eta_y + p_{01} + p_{10})} \left( 1 - e^{-(r_b - \pi - \eta_y + p_{01} + p_{10})(\tau - t)} \right).$$

For the original guess to be correct, we need to cross-check whether prs (B10) and (B11) satisfy equation (B2). Substituting (B10) and (B11) back into equation (B2) shows that equation (B2) does indeed hold. Equations (B10) and (B11) resemble equations (9) and (10) in the main text.

### Appendix C: Derivation Equation (24)

We normalize  $P^*$  to be 1. Equations (19), (22) and (23) then give us

$$(C1) \quad r_s = r_s^* + \frac{\beta_1}{\beta_0 + \beta_1 B_s} \left[ y_s P_s \left( -\delta^1 - \frac{p_{10}(\delta^0 - \delta^1)}{r_s - \pi - \eta_y + p_{01} + p_{10}} \right) + r_s B_s \right]$$

and

$$(C2) \quad \alpha_1 \ln r_s = \alpha_1 \ln \left( r_s^* + \frac{\beta_1}{\beta_0 + \beta_1 B_s} \left[ y_s P_s \left( -\delta^1 - \frac{p_{10}(\delta^0 - \delta^1)}{r_s - \pi - \eta_y + p_{01} + p_{10}} \right) + r_s B_s \right] \right)$$

We assume that the central bank counters the effects on the money supply via sterilisation. Notice that prior to the sudden stop, we have

$$(C3) \quad m - p^* - \ln(1) = m - p^* = \alpha_0 - \alpha_1 \ln r_s^*$$

From equation (C2) we know that after the attack the solution is

$$(C4) \quad m - p^* - s = \alpha_0 - \alpha_1 \ln \left( r_s^* + \frac{\beta_1}{\beta_0 + \beta_1 B_s} \left[ y_s P_s \left( -\delta^1 - \frac{p_{10}(\delta^0 - \delta^1)}{r_s - \pi - \eta_y + p_{01} + p_{10}} \right) + r_s B_s \right] \right)$$

and thus

$$(C5) \quad s = \alpha_1 \ln \left( r_s^* + \frac{\beta_1}{\beta_0 + \beta_1 B_s} \left[ y_s P_s \left( -\delta^1 - \frac{p_{10}(\delta^0 - \delta^1)}{r_s - \pi - \eta_y + p_{01} + p_{10}} \right) + r_s B_s \right] \right) - \ln r_s^*$$

Therefore, we have the solution for the exchange rate as follows:

$$(C6) \quad \ln S = \alpha_1 \ln \left( 1 + \frac{\beta_1}{\beta_0 + \beta_1 B_S} \left[ \gamma_S P_S \left( -\delta^1 - \frac{p_{10}(\delta^0 - \delta^1)}{r_S - \pi - \eta_Y + p_{01} + p_{10}} \right) + r_S B_S \right] \right)$$

This completes the proof.