The Puzzling Behavior of Spreads during Covid*

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Abstract

Advanced economies borrowed substantially during the Covid recession to fund their fiscal policy. The Covid recession differed from the Great Recession in that sovereign debt markets remained calm and spreads barely responded. We study the experience of Greece, the most extreme manifestation of the puzzling behavior of spreads during Covid. We develop a small open economy model with long-term debt and default, which we augment with official lenders, heterogeneous households and sectors, and Covid constraints on labor supply and consumption demand. The model is quantitatively consistent with the observed boom-bust cycle of Greece before Covid and salient observations on macro aggregates, government debt, and the sovereign spread during Covid. The spread is stable despite a rise in external borrowing during Covid, because lockdowns were perceived as transitory and the bailouts of the 2010s had tilted the composition of debt at the beginning of Covid away from defaultable private debt. The ECB's policy of purchasing debt in secondary markets during Covid did not stabilize spreads so much, but allowed the government to provide transfers that reduced inequality.

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1 Introduction

According to the International Monetary Fund (IMF), GDP of advanced economies contracted by 4.2 percent in 2020.[1] To combat the Covid recession, governments borrowed significantly to finance fiscal stimulus programs. As a result, between 2019 and 2020, government debt relative to GDP of advanced economies increased by almost 20 percentage points. The changes in GDP and government debt during Covid were as significant as those observed during the Great Recession, when advanced economies' GDP fell by 3.4 percent and their debt-to-GDP ratio increased by roughly 20 percentage points. However, in contrast to the sovereign debt crises of the Great Recession in the periphery of the eurozone, sovereign debt markets in advanced economies during Covid did not experience turbulence. The goal of this paper is to understand why this time was different. Why did sovereign spreads not increase during Covid, despite countries engaging in fiscal expansions that were as significant as past expansions that were accompanied by turbulence in sovereign debt markets?

To answer our question, we study the experience of Greece. Figure 1 shows the evolution of the Greek sovereign spread and debt-to-GDP ratio since 2000. After joining the euro area, Greece was borrowing at a spread of less than one percentage point over the interest rate paid by the German government. Greece's government debt-to-GDP ratio started increasing significantly in 2007 and reached almost 200 percent in 2011. Its sovereign spread started increasing in late 2008 and reached roughly 20 percentage points in 2011. The Covid stimulus in 2020 elevated Greece's debt-to-GDP ratio to an all-time high, but its spread barely responded.

Greece is an ideal case study for several reasons. Like other advanced economies, Greece experienced a significant recession in 2020, with GDP falling by 9 percent, and expanded its fiscal policy dramatically, leading to a roughly 25 percentage points rise in its debt-to-GDP ratio. Furthermore, shortly before Covid, Greece experienced a sovereign debt crisis during a macroeconomic contraction of unprecedented magnitude (Gourinchas, Philippon, and Vayanos, 2016; Chodorow-Reich, Karabarbounis, and Kekre, 2023). While the puzzling pattern of stable spreads despite rising debt levels is not unique to Greece, Greece is the most extreme manifestation of the puzzle. It had the highest external debt-to-GDP ratio in the world and experienced a sovereign debt crisis just a decade before Covid. Yet, Greece was able to borrow massively again during the Covid recession, without an increase in its borrowing costs.

To give a sense of the magnitude of the missing Greek spread during Covid, we examine the statistical relationship between spreads, debt, and other variables in samples of advanced

[1] The data for the tabulations in this paragraph are from the October 2023 version of the World Economic Outlook (https://shorturl.at/efp78).

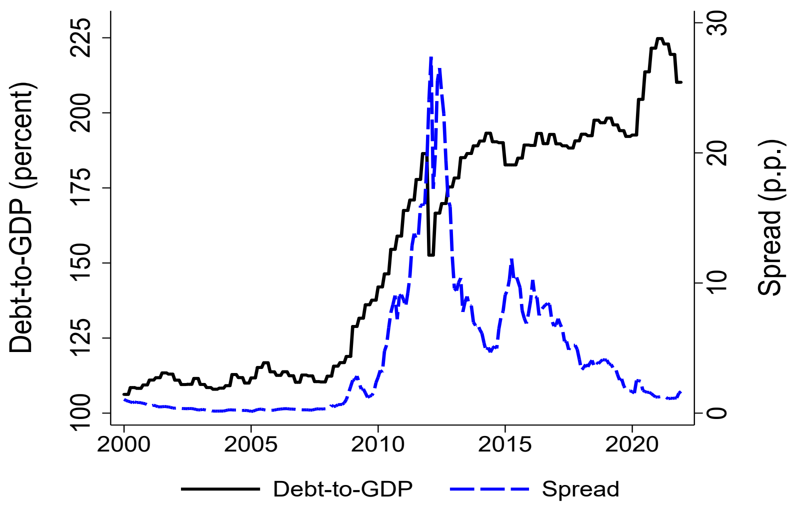


Figure 1: Greek Debt-to-GDP Ratio and Sovereign Spread

economies before Covid. The predictions using samples that include the Greek sovereign debt crisis of the 2010s generate an upper bound on the missing spread, because they project from the previous Greek experience, which features the strongest statistical association between the spread and debt and the largest persistent depression of the past 60 years among middle- and high-income economies. Using only the experiences of Ireland, Italy, Portugal, and Spain, we instead obtain a lower bound. Pooling across samples and specifications, we find a missing spread of around 4 percentage points, with a lower bound of around 2 percentage points and an upper bound of around 7 percentage points. Using these estimates, we can pose our research question more precisely: Why did the historical relationships that predict a roughly 4 percentage points increase in the Greek spread break down during Covid?

We begin by developing a model that aims to account for the experience of Greece both before and during Covid. We augment a standard small open economy model of long-term debt and default with four elements that allow us to accommodate several different forces that could plausibly account for the stability of the spread.[2] First, we introduce official lenders that provide bailout loans to the government. These loans have a longer maturity and a lower coupon rate than the debt held by private investors and are risk-free. The government anticipates that official lenders may provide loans during debt crises, and this expectation affects its incentives to accumulate debt and the price of the debt that it issues. We use the words "loans" and "bailouts" interchangeably, and include in them both the loans that were extended to Greece

[2] These elements aside, the model is similar to Chatterjee and Eyigungor (2012). This is also the baseline model described in Aguiar, Chatterjee, Cole, and Stangeby (2016) without rollover risk and risk-averse foreign investors.

in the 2010s as part of the economic assistance programs and the direct purchases of Greek sovereign debt by the European Central Bank (ECB) in secondary markets beginning in 2020 through the Pandemic Emergency Purchase Programme (PEPP).

Second, in addition to internationally traded goods, we model a non-traded sector that produces domestically consumed goods, because Covid lockdowns had a disproportionate impact on some types of services that are not traded. Third, motivated by the significant transfers that Greek households received both in the boom of the 2000s and during Covid, we model two types of households and introduce a motive for the government to redistribute income. The first type is optimizing households, which have access to an internationally traded risk-free bond that allows them to smooth their consumption over time. The second type is hand-to-mouth households, which cannot access asset markets, have lower labor income than the optimizing households, and are disproportionally affected by lockdowns because of their limited ability to work from home. Finally, in our production economy, the private sector responds to government policies by changing its savings and labor supply, which introduces a meaningful trade-off for the government when choosing the optimal level of redistribution.

We quantify the model and show that it does a good job of generating the observed boom of the 2000s, the bust of the 2010s, and the dynamics of the debt-to-GDP ratio and the spread both in the 2000s and in the 2010s. In doing so, we depart from the typical strategy for quantifying sovereign default models, which is to compare averaged model outcomes to averaged statistics in the data over a long sample or close to default episodes.[3] Instead, we map, in a detailed way, exogenous and endogenous model variables to their data counterparts, feed the measured exogenous variables into the model, and evaluate the model's performance in terms of matching the time series of the endogenous variables in the whole sample. While this process is more elaborate than typical strategies followed by the literature, our approach has two advantages. First, by feeding in the exogenous shocks as measured in the data before solving the model, we remove degrees of freedom from the researcher when it comes to generating boom-bust cycles and sovereign debt crises. Second, we assess the model's performance more comprehensively than it is done in the literature, as we compare production, consumption, private assets, transfers, sovereign debt, and spreads in the model to the observed time series throughout our sample period.

Covid lockdowns take the form of two constraints, one limiting the non-traded goods that can be consumed in 2020 and the other limiting the labor that hand-to-mouth households can

[3] For example, see the quantification of typical models described in Aguiar, Chatterjee, Cole, and Stangeby (2016).

provide in 2020. In our open economy model, the supply-side constraint is important for generating the drop in production, and the demand-side constraint is important for generating the drop in consumption. We discipline our quantitative exercises by requiring that the parameters of the economy before Covid be held constant when we assess the performance of the model during Covid. Despite this discipline, we find that the model matches very closely the increase in transfers and government debt in 2020 and 2021, while at the same time generating stable spreads in both years. The model also matches the observed increase in private savings in 2020 and the observed rebound of consumption and output in 2021.

We illustrate that the constraint on labor supply is mostly responsible for the substantial increase in transfers and government debt during Covid. The mechanism is that lockdowns disproportionally affect hand-to-mouth households in 2020, so the government provides insurance by transferring resources to them. However, some transfers spill over to optimizing households. Since optimizing households face a binding constraint on consuming non-traded goods and anticipate that the rise in transfers is transitory, they save the additional resources. When lockdowns are lifted in 2021, optimizing households increase their consumption substantially, and the government continues to provide higher transfers to hand-to-mouth households, which reduce inequality.

Having developed a model that generates a significant recession, a significant increase in both government borrowing and private savings, and stable spreads during Covid, we run a horse race to assess which of the competing explanations accounts for the missing spread during Covid. Quantitatively, the most important factor for the low spread is the belief that lockdowns would not persist for longer. To be precise, by "belief" we mean the expectation of how lockdowns would evolve after 2020 and not whether lockdowns actually occurred after 2020. The incidence of lockdowns also matters for spreads, but their expected duration is quantitatively more important. The mechanism by which a higher expected duration of lockdowns increases the spread is subtle and specific to the nature of the Covid shock. If the 2020 recession had been caused by a productivity shock, the expected duration of the shock would not have played an important role for the spread. The difference between lockdowns and productivity shocks is that lockdowns are redistributive in nature, because in the absence of a policy intervention, they hit hand-to-mouth households hardest. Had lockdowns been perceived as more persistent, foreign investors would have anticipated more redistribution by the government in the future, which would have pushed the economy closer to default with a higher spread and lower equilibrium borrowing.

The second most important factor in generating a low spread during Covid is the old bailouts that Greece received during the 2010s. By old bailouts, we mean the official loans provided to Greece under the economic assistance programs. Whereas in the 2000s, less than 20 percent of Greek government debt was from official lenders, that proportion rose to more than 60 percent by the end of 2019. In a counterfactual world in which these loans had not been extended in the 2010s, Greece would have entered Covid with a debt composition that was tilted toward defaultable private debt, and the spread would have increased more during Covid. Similarly, as part of the economic adjustment programs in the 2010s, Greece wrote down less than half of its private debt. If prevailing policies had extracted more debt relief from private investors, expectations for future haircuts in 2020 would have been higher, and the spread would have increased by significantly more during Covid.

By contrast, we find a smaller role for the PEPP. The ECB's purchases of Greek debt in secondary markets were roughly 10 percent of GDP in both 2020 and 2021. In their absence, spreads would have increased, but by less than the lower bound predicted by the historical relationship between the spread and debt. This occurs because removing ECB purchases leads the government, in equilibrium, to borrow significantly less in order to moderate the rise of the spread. We conclude that ECB purchases did not stabilize spreads so much, but they allowed the government to provide increased transfers to households, which reduced inequality.

We find a negligible role for moral hazard in keeping spreads stable, because debt crises and significant extensions of loans are rare events. Changes in the maturity of private debt issuance, changes in the risk-free rate, and private sector responses also play a limited role in stabilizing the spread. Finally, we study interactions among various forces. While the ECB purchases in 2020 are not quantitatively important on their own for stabilizing the spread, removing these purchases and increasing the expected duration of lockdowns raises the spread to levels closer to the ones observed during the sovereign debt crisis of the 2010s. A policy implication of our findings is that ECB policies during Covid mostly ameliorated inequality, but would have averted a sovereign debt crisis had investors perceived lockdowns as more persistent.

Our paper contributes to several strands of literature. We extend the research frontier of sovereign default models in the spirit of Eaton and Gersovitz (1981), Arellano (2008), and Chatterjee and Eyigungor (2012) to include heterogeneous households and sectors, private savings, redistributive motives for the government, official lenders, and Covid lockdowns.[4] While

[4] Gordon and Guerron-Quintana (2018) also consider a production economy by including capital in their model. They study a social planner's problem that can be decentralized under suitable lump-sum transfers to a representative household. A difference with their paper is that private savings constrain the government in our model, because transfers also accrue to households that do not have access to private savings. Arellano, Bai, and Mihalache (2018) extend the model with capital accumulation to a two-sector environment that accounts for the observation that non-traded production declines more than traded production during sovereign debt

most of these elements separate us from papers such as Bocola, Bornstein, and Dovis (2019) and Bocola and Dovis (2019), we share with them our focus on the experience of advanced economies, and in particular the eurozone, rather than the experiences of emerging markets, which originally motivated the sovereign default literature. As discussed earlier, a contribution of our paper is to further develop the quantitative implementation of sovereign debt models by more thoroughly mapping our model to the data and by more comprehensively assessing the model's performance.

An emerging literature tries to understand how official lending impacts sovereign borrowing in private markets. Callegari, Marimon, Wicht, and Zavalloni (2023) and Liu, Marimon, and Wicht (2023) consider how a financial stability fund can improve allocations by offering a long-term contingent contract to a country that cannot commit to repaying its debt. We are focused on the quantitative effects of and the fiscal policy responses to bailouts, rather than on their optimal design, and thus we take bailout policies as given from the data without modeling the problem faced by the official lender. In a standard sovereign default model, Fink and Scholl (2016) demonstrate that bailouts reduce default risk in the short term at the cost of increasing the long-run probability of default as countries accumulate more debt. The authors also demonstrate that conditioning loans on some modest level of fiscal discipline lowers the long-run probability of default. Our model is similar to theirs in that government incentives to borrow are affected by the possibility of official loans. However, we abstract from conditionality in fiscal policy because PEPP did not impose conditions on fiscal policy.

Our model predicts an increase in the spread by 0.5 percentage point in 2020 in the absence of the purchases of sovereign debt by the ECB. In the absence of the 2010s loans, the model generates a roughly 2 to 2.5 percentage points increase in the spread between 2012 and 2018. Our estimates come from a structural model with equilibrium adjustments and specific mechanisms, and thus are not directly comparable to empirical estimates of the effects of asset purchases on sovereign spreads that do not include equilibrium adjustments but include other channels by which purchases affect spreads. Despite these differences, we document that empirical estimates of the effects of asset purchases on spreads (Trebesch and Zettelmeyer, 2018; Rostagno, Altavilla, Carboni, Lemke, Motto, and Saint-Guilhem, 2021) are quantitatively consistent with our model-based counterfactuals of the effects of official lending on the Greek spread.

Our paper contributes to the study of fiscal policy during recessions in the presence of sovereign risk.[5] Bianchi, Ottonello, and Presno (2023) study a model with nominal rigidity and

crises. Sosa-Padilla (2018) studies the interaction between sovereign debt crises and banking crises in a closed economy model of default, private capital accumulation, and distortionary labor taxation.

[5]In an early contribution, Cuadra, Sanchez, and Sapriza (2010) develop a model with endogenous fiscal policy

uninsurable unemployment risk for hand-to-mouth households. Despite these elements, which tend to make countercyclical fiscal policy optimal, the authors demonstrate that such a policy may be undesirable because it increases the probability of a debt crisis during a recession. In our model, transfers to poor households decline substantially in the recession of the 2010s, because the government is excluded from international financial markets and does not have enough resources to sustain transfers. However, transfers increase substantially during Covid. Consistent with their insights, we illustrate that the optimality of expanding fiscal policy in a recession is state dependent. Had Greece entered the Covid period with a larger stock of private debt and a lower stock of official loans, transfers would have been substantially smaller. Further, in our model, the ECB's purchases of sovereign debt provide a buffer that the government uses to expand its fiscal policy during Covid. Another difference from their paper is that the redistributive nature of the Covid recession is key for how fiscal policy responds to it, and that response is qualitatively different from the response with respect to standard productivity shocks.[6]

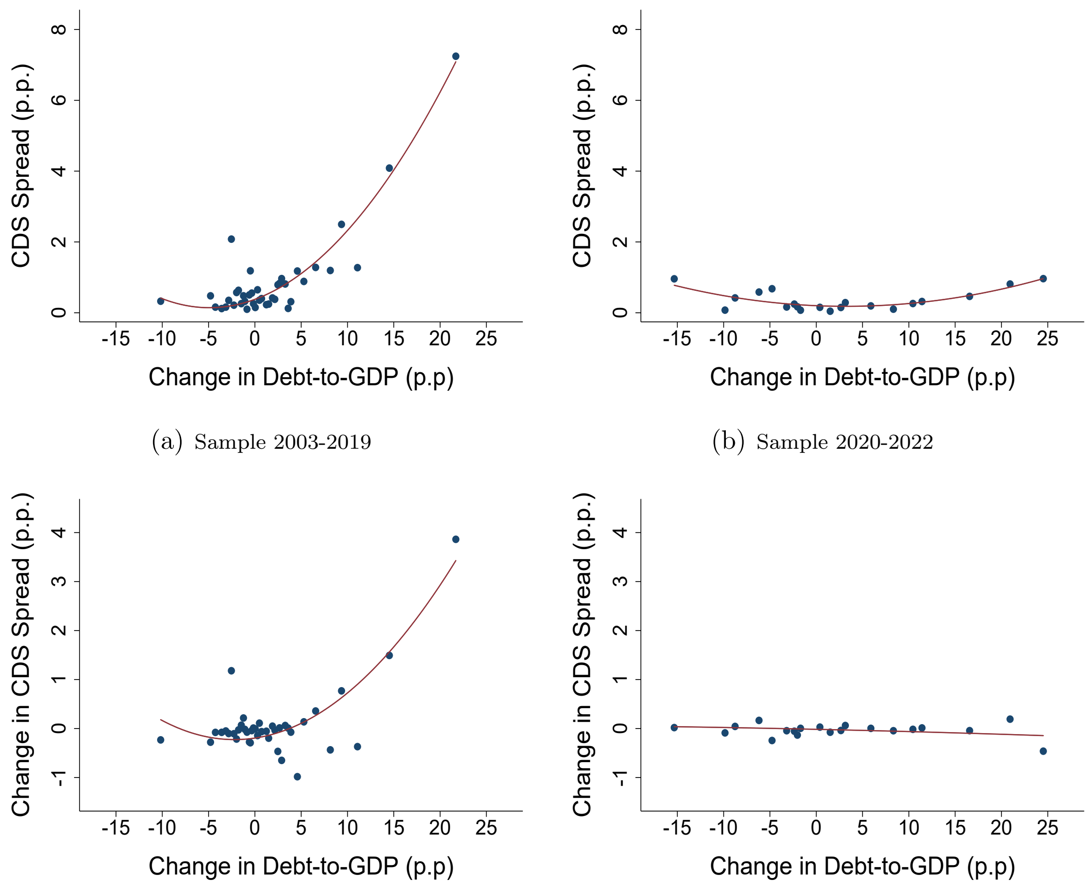
2 Some Observations on Sovereign Spreads and Debts

We begin by presenting some observations on the relationship between sovereign spreads and government debt. We restrict our analysis to the group of advanced economies, which is the relevant comparison group for Greece. In Figure 2 we present the cross-sectional relationship between the five-year CDS spread and the change in the debt-to-GDP ratio.[7] The left panels show this relationship for the sample before Covid, covering the years between 2003 and 2019.

and sovereign risk, and establish that public spending is procyclical and tax rates are countercyclical. Arellano and Bai (2017) study the Greek crisis and show that a rise in tax revenues does not prevent sovereign default because they are used to finance public consumption.

[6] Arellano, Bai, and Mihalache (2023) study debt relief programs in emerging markets during Covid, in a framework that integrates epidemiological dynamics into sovereign default models. Unlike advanced economies, emerging markets had less fiscal space to transfer resources to households and thus the authors find substantial benefits from relief programs that eased financial constraints. We instead find that the ECB's intervention had a modest impact on spreads but a larger impact on the consumption of poor households. Motivated by the European sovereign debt crisis, D'Erasmo and Mendoza (2021) study the distributional motive of a government to not repay its debt in a model in which households have uninsurable risk and hold government debt. We abstract from such a motive, because for the case of Greece, most government debt is held externally. Instead, we focus on redistribution by way of government transfers, which was the primary policy instrument used to address the impact of Covid.

[7] For this figure, we use the fiscal space database from the World Bank (Kose, Kurlat, Ohnsorge, and Sugawara, 2022). The CDS spread data come from Bloomberg and J.P. Morgan. We use CDS spreads relative to Germany. We exclude countries for which less than 10 percent of government debt is held externally, a criterion which drops Switzerland and Japan from the sample. To improve the visibility of the figure, we also exclude observations with spreads higher than 100 percentage points, a criterion that drops Greece in 2012 from the sample.



(a) Sample 2003-2019

(b) Sample 2020-2022

(c) Sample 2003-2019

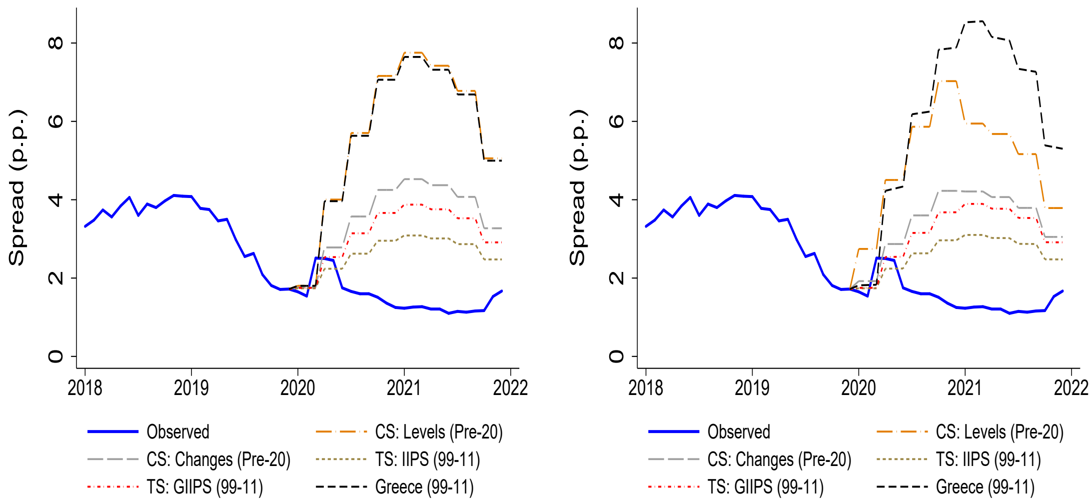
(d) Sample 2020-2022

Figure 2: Cross Section of CDS Spreads and Debt-to-GDP Ratios

Each dot represents the average CDS spread for a bin of countries that consists of 2.5 percent of observations, where observations are sorted according to their annual change in the debt-to-GDP ratio in the horizontal axis. The right panels show the same relationship for the Covid sample, covering the years between 2020 and 2022. Each bin of countries consists of 5 percent of observations, as we have fewer observations in this shorter sample. In both figures we fit a quadratic relationship.

Beginning with the top left panel, we observe that the CDS spread is uncorrelated with changes in the debt-to-GDP ratio for negative changes in the debt-to-GDP ratio. The spread increases as the debt-to-GDP ratio becomes positive, reaching almost 8 percentage points for countries that experience a 20 percentage points change in their debt-to-GDP ratio.[8] The bottom left panel confirms that the same convex relationship arises between the annual change

[8]Greece during its sovereign debt crisis is a member of this bin. Other countries with relatively high spreads and changes in their debt-to-GDP ratios are Ireland, Italy, Portugal, and Spain during the euro debt crisis and Cyprus in 2015.



(a) Predictor: Debt/GDP

(b) Predictors: Debt/GDP and GDP

Figure 3: Actual vs Predicted Spread for Greece

in the spread and the annual change in the debt-to-GDP ratio, but the maximum change in the spread is now 4 percentage points.

In the right panels, for the Covid period, we observe that the range of values for the change in the debt-to-GDP ratio is similar to the one in the left panels for the period before Covid. Several governments during Covid increased their debt ratio by around 20 percentage points relative to GDP. Despite the significant changes in the debt-to-GDP ratio during Covid, spreads are low. No advanced economy in the world experienced a spread higher than 2 percentage points, and the spread is uncorrelated with the debt-to-GDP ratio.

Figure 3 quantifies the puzzling behavior of the spread for the case of Greece. The solid blue line presents the observed Greek sovereign spread between 2018 and 2021. The other lines predict the Greek spread from 2020 onward, using the historical behavior of sovereign spreads before 2020. The lines "CS: Levels (Pre-20)" and "CS: Changes (Pre-20)" in the left panel of Figure 3 predict the Greek spread using the linear relationship between the level or the change in the spread and the change in the debt-to-GDP ratio for the observations that underlie the binscatters of the left panels of Figure 2. The lines "CS: Levels (Pre-20)" and "CS: Changes (Pre-20)" in the right panel of Figure 3 predict the Greek spread using the same relationship but also add the change of log GDP as a predictor. The other three lines use time series variation before the euro debt crisis, for a sample that only includes only Ireland, Italy, Portugal, and Spain ("TS: IIPS (99-11)"), a sample that adds Greece to these four countries ("TS: GIIPS (99-11)"), and a sample that covers only Greece ("Greece: 99-11"). As the figures show, predicting solely on the experience of other euro countries with turbulence in their sovereign debt markets produces a lower prediction of the increase in the spread. By contrast, including the Greek experience before the 2012 default significantly raises the predicted spread.[9]

To summarize, from the historical relationship between spreads and debt-to-GDP ratios, we predict that the increase in Greece's debt-to-GDP ratio during Covid should have been associated with a spread that rises to roughly 5.5 percentage points, when averaged across estimation methods.[10] The observed spread is, however, well below 2 percentage points after the second half of 2020. The remainder of the paper attempts to understand why the historical relationship broke down during Covid.

3 Model

We first describe the economy for the period between 2002 and 2019, which includes the boom in the 2000s and the sovereign debt crisis in the 2010s, but not the Covid recession. We use this period to parameterize the model and assess the plausibility of its mechanisms. Later, we extend the environment to model the economic impacts of lockdowns and to perform counterfactuals during Covid.

3.1 Population

Time is discrete and the horizon is infinite, $t = 0, 1, 2, ...$ The domestic economy is small and populated by a measure one of households, a representative firm in each sector, and a government.[11] There are two types of households, $j = \{o, h\}$. The key difference between them is that households o optimize their consumption intertemporally, while households h consume hand-to-mouth their after-tax-and-transfer income. There are two sectors $i = \{T, N\}$, with sector T producing internationally traded goods and sector N producing domestically consumed non-traded goods. In addition to these domestic participants, there is a continuum of international investors that hold and price government private debt, as well as official lenders

[9]The data for the time series predictions in Figure 3 come from the ECB's Interest Rate Statistics and are the same data underlying the series shown previously in Figure 1. For the time series regressions with more than one country, we include time and country fixed effects in a regression of the spread on the debt-to-GDP ratio and log GDP. We have confirmed the robustness of our results to including alternative or additional controls such as GDP growth, the trade balance, the primary deficit, and an index of political risk.

[10]Our range of estimates is consistent with the estimates reported by Cruces and Trebesch (2013). The authors estimate how spreads comove with the debt-to-GDP ratio for a larger set of countries that includes emerging markets and for a longer sample. Using their estimated coefficient on debt-to-GDP, we would predict that the Greek spread rises to around 4.5 percentage points during Covid.

[11]The economy is small in the sense that it takes as given the price of traded goods and the interest rate on savings. Traded goods serve as the numeraire, with a world price equal to one.

that may extend loans to the government.

3.2 Timing of Events

Vector s_t collects the state variables at the beginning of the period. The government moves first and decides whether to restructure the debt held by foreign investors. Conditional on not restructuring its debt, it chooses how much new debt to issue and how many resources to transfer to households. If the government decides to restructure its debt, it may receive a loan from official lenders. After the government makes its decisions, households choose their consumption, labor, and assets, firms choose their output and inputs, foreign investors price the government debt, and labor and non-traded goods markets clear. Private decisions depend on the vector x_t, which includes s_t and all other variables realized after the government makes its decisions.

3.3 Households

A measure γ of households are type o, "optimizing," and use savings to smooth their consumption intertemporally. They choose their consumption of traded goods c_T, consumption of non-traded goods c_N, labor supply ℓ, and assets a to maximize the expected sum of discounted utility flows,

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_c^t \left(\frac{g_t}{\bar{g}}\right)^{\alpha} \left[\frac{c(.)^{1-\sigma}-1}{1-\sigma} - \frac{\chi^o}{1+1/\varepsilon}(\ell_t^o)^{1+1/\varepsilon}\right], \tag{1}$$

where parameter $\beta_c \in (0,1)$ is households' discount factor, parameter $\sigma \geq 0$ is the coefficient of relative risk aversion, parameter $\chi^o > 0$ is the disutility of work, and parameter $\varepsilon \geq 0$ is the Frisch elasticity of labor supply.

The factor $(g_t/\bar{g})^{\alpha}$ that multiplies the bracket is the utility effect of exogenous government consumption g, normalized by some constant level $\bar{g}$. Parameter α allows us to consider in a flexible way how government consumption affects the private marginal utility of consumption. When $\alpha = 0$, private and government consumption are separable. Government consumption increases the private marginal utility of consumption when $\alpha > 0$, and the opposite when $\alpha < 0$. The same factor $(g_t/\bar{g})^{\alpha}$ multiplies both the utility of consumption and the disutility of labor, so that government consumption does not mechanically generate a labor wedge in the work decision.[12]

[12] For equilibrium allocations and prices, the only relevant consideration is whether government consumption is a complement or a substitute to private consumption, and not whether government consumption increases or decreases the level of utility. To consider the welfare effects of government consumption, we could add a

The consumption aggregator in the utility function is

$$c_t^o = \left(\omega_c^{\frac{1}{\phi}}(c_{Tt}^o)^{\frac{\phi-1}{\phi}} + (1-\omega_c)^{\frac{1}{\phi}}(c_{Nt}^o)^{\frac{\phi-1}{\phi}}\right)^{\frac{\phi}{\phi-1}}, \tag{2}$$

where $\omega_c \in (0,1)$ is the weight on traded goods and $\phi \geq 0$ is the elasticity of substitution between traded and non-traded goods. The budget constraint of optimizing households is

$$c_{Tt}^o + p_{Nt}c_{Nt}^o + a_{t+1}^o = (1-\tau_t)w_t\theta^o\ell_t^o + (1+r)a_t^o + T_t^o, \tag{3}$$

where p_{Nt} is the price of non-traded goods relative to traded goods, τ_t is the exogenous tax rate on labor income, w_t is the wage per efficiency unit of labor, parameter $\theta^o > 0$ is the production efficiency of optimizing households, parameter $r > 0$ is the risk-free return on savings, and T_t^o is the government's transfers to optimizing households. Optimizing households cannot borrow: $a_{t+1}^o \geq 0$.[13]

A measure $1-\gamma$ of households are type h, "hand-to-mouth," without access to assets. They choose consumption and labor supply to maximize the expected sum of discounted utility flows,

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta_c^t \left(\frac{g_t}{\bar{g}}\right)^{\alpha} \left[\frac{c(.)^{1-\sigma}-1}{1-\sigma} - \frac{\chi^h}{1+1/\varepsilon}(\ell_t^h)^{1+1/\varepsilon}\right], \tag{4}$$

subject to the sequence of budget constraints

$$c_{Tt}^h + p_{Nt}c_{Nt}^h = (1-\tau_t)w_t\theta^h\ell_t^h + T_t^h, \tag{5}$$

where T_t^h are government's transfers to hand-to-mouth households. To introduce inequality considerations into the model, we allow hand-to-mouth households to have different production efficiency $\theta^h > 0$ and disutility of work $\chi^h > 0$ from those of optimizing households. We motivate this modeling choice with the observation that the Greek government transferred significant resources to poorer households during our sample period.

3.4 Firms

Firms are perfectly competitive and operate linear technologies that transform labor into output. In the traded sector, the profit maximization problem of the representative firm is

$$\max_{\ell_{Tt}\geq 0} \Pi_{Tt} = y_{Tt} - w_t\ell_{Tt}, \quad \text{subject to} \quad y_{Tt} = z_{Tt}\ell_{Tt}, \tag{6}$$

separable term in preferences that depends only on government consumption in order to distinguish between complementarities and level effects of government consumption.

[13] The asset a is a risk-free international bond and does not represent claims to the government's bonds. Most of Greek debt is held externally, and so we simplify the model by assuming that domestic households do not hold government debt. For example, in 2019, 89 percent of Greek government liabilities were held externally.

where y_{Tt} is traded production, ℓ_{Tt} is total efficiency units of labor employed in the traded sector, and z_{Tt} is exogenous traded productivity. In the non-traded sector, the profit maximization problem of the representative firm is

$$\max_{\ell_{Nt} \geq 0} \Pi_{Nt} = p_{Nt} y_{Nt} - w_t \ell_{Nt}, \quad \text{subject to} \quad y_{Nt} = z_{Nt} \ell_{Nt}, \tag{7}$$

where y_{Nt} is non-traded production, ℓ_{Nt} is total efficiency units of labor employed in the non-traded sector, and z_{Nt} is exogenous non-traded productivity.

The linearity in production simplifies the computation of the model, because it allows us to pin down the wage per efficiency unit of labor and the relative price of non-traded goods as a function of productivities when both sectors operate in equilibrium. In this case, we obtain $w_t = z_{Tt}$ and $p_{Nt} = z_{Tt}/z_{Nt}$.

3.5 Government

The government purchases g_T traded goods and g_N non-traded goods that provide utility to households.[14] It transfers T^o resources to optimizing households and T^h resources to hand-to-mouth households. The government raises revenue by taxing labor income at an exogenous rate of τ. To cover any gap between spending and tax revenues, the government borrows internationally.

One type of external financing is long-term debt b issued to competitive, risk-neutral foreign investors at a price of q. While in good credit standing, the maturity rate of this debt is $\lambda_p > 0$ and its coupon rate is $\kappa_p > 0$. While in bad credit standing, the maturity rate of this debt is $\lambda_d > 0$ and its coupon rate is $\kappa_d > 0$. Another type of external financing is loans f from official lenders. The maturity rate of loans is $\lambda_g > 0$ and their coupon rate is $\kappa_g = r$. A crucial difference between b and f is that the former is defaultable, whereas the latter is not. We think this is a reasonable assumption, because research shows that official loans from multilateral organizations have higher seniority than debts held by private lenders.[15] Thus, f is risk-free and its actuarially fair price equals one. Changes in the flow of loans can be triggered endogenously, by the government's decision to restructure, or exogenously, by the passage of time.

In each period, the first decision of the government is whether to restructure its debt, $\eta_{t+1} = \{0, \bar{\eta}\}$. Restructuring debt is associated with a haircut $\bar{\eta} \in [0, 1]$ on b_{t+1} and new maturity rate λ_d and coupon rate κ_d for the remaining debt. Restructuring may trigger a

[14] The government consumption aggregator g is Cobb-Douglas in g_T and g_N, with traded share parameter ω_g.

[15] See Schlegl, Trebesch, and Wright (2019) for evidence on the seniority of the IMF and the World Bank and Trebesch and Zettelmeyer (2018) for evidence on the seniority of the ECB.

flow of official loans equal to $\hat{\delta}_t$. Official loans $\hat{\delta}_t|(\eta_{t+1}, \delta_t)$ are a random variable, with their distribution depending on both the government's restructuring decision η_{t+1} and the loans δ_t that are announced in the beginning of the period. Finally, restructuring debt is associated with a utility cost $C(\eta_{t+1}, s_t)$ for the government and exclusion from issuing debt for at least the current period.

We distinguish between restructuring η_{t+1}, which is the control variable of the government, and the credit standing of the government at the beginning of each period d_t, which is the state variable. The two variables are linked by the law of motion

$$d_{t+1} = \begin{cases} 0 & \text{if } \eta_{t+1} = 0 \text{ and } d_t = 0, \\ 0 & \text{if } \eta_{t+1} = \bar{\eta} \text{ or } d_t = 1, \quad \text{with probability } \psi, \\ 1 & \text{if } \eta_{t+1} = \bar{\eta} \text{ or } d_t = 1, \quad \text{with probability } 1-\psi. \end{cases} \tag{8}$$

If the government enters a period in good credit standing ($d_t = 0$) and does not restructure its debt ($\eta_{t+1} = 0$), then it always enters next period in good credit standing ($d_{t+1} = 0$). If the government enters a period in bad credit standing ($d_t = 1$) or restructures its debt ($\eta_{t+1} = \bar{\eta}$), then with probability $\psi \in [0, 1]$ it regains access to markets in the next period ($d_{t+1} = 0$) and with probability $1 - \psi$ it enters the next period in bad credit standing ($d_{t+1} = 1$).

We now describe the maximization problem of a government that begins the period in good credit standing and chooses not to restructure its debt ($d_t = \eta_{t+1} = 0$). At this point, the flow of loans $\hat{\delta}_t$ has been realized, so the value of the government is

$$V^n(s_t, \eta_{t+1}, \hat{\delta}_t) = \max_{b_{t+1}, T_t} \left\{ \zeta U_t^o + (1-\zeta) U_t^h + \beta_g \mathbb{E}_t V(s_{t+1}) \right\}, \tag{9}$$

where the parameter $\beta_g \in (0, 1)$ is the government's discount factor and the parameter $\zeta \in [0, 1]$ is the weight that the government places on the utility of optimizing households, which may differ from their share γ in the population. The continuation value $V(s_{t+1})$ denotes the value of the government at the beginning of the next period and is defined below.

The government is subject to the budget constraint,

$$g_{Tt} + p_{Nt} g_{Nt} + T_t + (\lambda_p + \kappa_p) b_t + (\lambda_g + \kappa_g) f_t = \tau_t y_t + q_t (b_{t+1} - (1-\lambda_p) b_t) + \hat{\delta}_t - i_t, \tag{10}$$

where $y_t = w_t \ell_t = y_{Tt} + p_{Nt} y_{Nt}$ is aggregate output in terms of traded goods and $i_t \geq 0$ is an issuance cost introduced for technical reasons (see Appendix B).

Total transfers are

$$T_t = \gamma T_t^o + (1-\gamma) T_t^h = \gamma \xi T_t^h + (1-\gamma) T_t^h, \tag{11}$$

where the parameter $\xi \geq 0$ controls the progressivity of the transfer system. When $\xi = 1$, the transfer to every optimizing household equals the transfer to every hand-to-mouth household. In our quantitative implementation, we have $\xi < 1$, which means that the transfer system is progressive, as each hand-to-mouth household receives more transfers than each optimizing household. We do not allow the government to tax in a lump-sum way optimizing households, because that would make the decision to redistribute uninteresting.

Finally, the law of motion for official loans is given by

$$f_{t+1} = (1 - \lambda_g) f_t + \hat{\delta}_t. \tag{12}$$

In choosing debt b_{t+1} and transfers T_t, the government internalizes the private sector equilibrium and the price of debt $q(s_t, \eta_{t+1}, \hat{\delta}_t, b_{t+1}, T_t)$ that ensue after its choices.

Next, we describe the maximization problem of a government that either begins the period in bad credit standing ($d_t = 1$) or decides to restructure its debt ($\eta_{t+1} = \bar{\eta}$). At this point, the flow of loans $\hat{\delta}_t$ has been realized, so the value of the government is

$$V^d(s_t, \eta_{t+1}, \hat{\delta}_t) = \max_{T_t} \Big\{ \zeta U_t^o + (1 - \zeta) U_t^h - C(\eta_{t+1}, s_t) + \beta_g \mathbb{E}_t V(s_{t+1}) \Big\}. \tag{13}$$

Similar to Bianchi, Ottonello, and Presno (2023), we specify the utility cost of default as $C = \mu + \mu_T \log(z_{Tt}) + \mu_N \log(z_{Nt})$ if $\eta_{t+1} > 0$ and zero otherwise. The government is subject to the budget constraint,

$$g_{Tt} + p_{Nt} g_{Nt} + T_t + (\lambda_d(\eta_{t+1}, \hat{\delta}_t) + \kappa_d(\eta_{t+1}, \hat{\delta}_t)) b_t + (\lambda_g + \kappa_g) f_t = \tau_t y_t + \hat{\delta}_t, \tag{14}$$

the law of motion for private debt,

$$b_{t+1} = (1 - \eta_{t+1})(1 - \lambda_d(\eta_{t+1}, \hat{\delta}_t)) b_t, \tag{15}$$

and the law of motion for official loans in equation (12). We allow the new maturity rate $\lambda_d(\eta_{t+1}, \hat{\delta}_t)$ and coupon rate $\kappa_d(\eta_{t+1}, \hat{\delta}_t)$ to depend on the country's restructuring decision and bailout state.[16] Again, the government internalizes the private sector equilibrium and the price of debt $q(s_t, \eta_{t+1}, \hat{\delta}_t, b_{t+1}, T_t)$ that ensue after its choices.

Finally, the government chooses whether to restructure its debt to maximize the value

$$V(s_t) = \max_{\eta_{t+1} \in \{0, \bar{\eta}\}} \Big\{ d_t \bar{V}^d(s_t, \eta_{t+1}) + (1 - d_t) \Big(\mathbb{I}\{\eta_{t+1} > 0\} \bar{V}^d(s_t, \eta_{t+1}) + \mathbb{I}\{\eta_{t+1} = 0\} \bar{V}^n(s_t, \eta_{t+1}) \Big) \Big\}.$$

[16] Dvorkin, Sanchez, Sapriza, and Yurdagul (2021) show that restructuring events are often associated with a significant increase in a country's debt maturity. Modeling λ_d and κ_d as a function of the restructuring decision and bailout state allows us to mimic the profile of payments and path of the debt during the 2010s.

The flow of official loans $\hat{\delta}_t$ is not known yet when the government contemplates restructuring its debt. Thus, the expected value under good credit standing is

$$\bar{V}^d(s_t, \eta_{t+1}) = \int V^d(s_t, \eta_{t+1}, \hat{\delta}_t) \mathrm{d}F(\hat{\delta}_t | \eta_{t+1}, \delta_t), \tag{16}$$

and the expected value under bad credit standing is

$$\bar{V}^n(s_t, \eta_{t+1}) = \int V^n(s_t, \eta_{t+1}, \hat{\delta}_t) \mathrm{d}F(\hat{\delta}_t | \eta_{t+1}, \delta_t), \tag{17}$$

where $F(\hat{\delta}_t | \eta_{t+1}, \delta_t)$ is the conditional distribution function of official loans.[17]

3.6 Foreign Investors

Foreign investors who hold the government's debt are risk-neutral and competitive. Therefore, the price of debt is actuarially fair and satisfies

$$\begin{aligned} q(x_t) &= \frac{1}{1+r}\mathbb{E}_t\Bigg[\Big((1-d_{t+1})\mathbb{I}\{\eta_{t+2}(s_{t+1})=0\}\Big)\Big[\lambda_p + \kappa_p + (1-\lambda_p)q(x_{t+1})\Big] \\ &+ \Big(d_{t+1} + (1-d_{t+1})\mathbb{I}\{\eta_{t+2}(s_{t+1})>0\}\Big)\Big[\lambda_d(\eta_{t+2}, \hat{\delta}_{t+1}) + \kappa_d(\eta_{t+2}, \hat{\delta}_{t+1}) \\ &+ (1-\eta_{t+2})(1-\lambda_d(\eta_{t+2}, \hat{\delta}_{t+1}))q(x_{t+1})\Big]\Bigg], \end{aligned} \tag{18}$$

where r is the same risk-free rate at which optimizing households save.

Changes in the price of debt reflect only changes in the expected payoff of debt, which includes the return of principal, coupon payment, the probability of default, and the haircut rate conditional on default. We abstract from the risk premium for two reasons. First, in Appendix A, we demonstrate that, under the null hypothesis that our model generates the data, the predicted sovereign spread tracks very closely the observed spread in the run-up to the Greek debt crisis of the 2010s. The prediction of the spread is based only on state variables of the model specific to Greece and not on creditor-side variables that determine the risk premium. We document two significant deviations of the observed spread from the predicted spread, one in 2012 and one in 2015, which we could interpret as an increase in the risk premium. However, model parameters are not estimated to match spread levels during

[17] The timing assumption, in which the government first decides whether to restructure and then issues new debt, excludes the possibility of self-fulfilling rollover crises. We view this as a reasonable assumption. Bocola and Dovis (2019) document that only about one-seventh of the rise of Italian spread between 2008 and 2012 reflects non-fundamental risk. The deterioration of fundamentals in Greece was much larger than the one in Italy. In the run-up to the crisis, we do not observe a lengthening of the maturity structure of Greek bonds, which would be suggestive of increased rollover risk.

these years. Second, with respect to the Covid period, one would need to argue that the risk premium *decreased* by 4 percentage points in order to rationalize the puzzle of the missing spread, which we find implausible. We note that the variation of spreads in the cross-sectional results presented in Section 2 absorbs common time-varying risk premia. In the time series results with more than one country in the sample, we additionally absorb fixed differences in risk premia across countries.

3.7 Equilibrium

The exogenous state variables, $z_T, z_N, g_T, g_N, \tau, \hat{\delta}, \delta$, include productivity, government consumption, the tax rate, and official loans. We specify the stochastic processes that govern these state variables in our quantitative implementation.

Given the exogenous state variables and their perceived stochastic processes, an equilibrium consists of allocations $c_i^j(x), \ell^j(x), \ell_i(x), a'(x)$ for $j = \{o, h\}$ and $i = \{T, N\}$, prices $w(x), p_N(x), q(x)$, and government policies $\eta'(s), b'(s, \hat{\delta}), T(s, \hat{\delta})$ such that (1) households maximize their values; (2) firms maximize their profits; (3) the government maximizes its value; (4) the non-traded goods market clears: $c_N + g_N = y_N$; and (5) the price of debt $q(x_t)$ satisfies the functional equation (18). The state vector at the beginning of the period is $s = (z_T, z_N, g_T, g_N, \tau, \delta, d, f, b, a)$, and the state vector after the government has made its decision is $x = (s, \eta', \hat{\delta}, b', T)$. Appendix C describes the computation of the equilibrium.[18]

4 Quantification

We begin by measuring model objects in the data. We continue by parameterizing the model so that model-generated outcomes match their data counterparts between 2002 and 2019, including the Greek boom in the 2000s and the sovereign debt crisis in the 2010s. Later, we extend the model to the Covid period and perform counterfactuals to evaluate the economic forces that determine spreads and other macroeconomic outcomes during that period.

[18]Given w and p_N, the market clearing condition in the non-traded sector pins down equilibrium labor ℓ_N. There is no equilibrium condition in the traded goods sector, because production that exceeds consumption is exported and production that falls short of consumption is imported. Net exports $\mathrm{nx}_t = y_{Tt} - c_{Tt} - g_{Tt}$ and the current account equals net exports plus net income and transfers from abroad (see Appendix B). For the traded sector to operate in equilibrium, $\ell_{Tt} = \gamma\theta^o\ell_t^o + (1-\gamma)\theta^h\ell_t^h - \ell_{Nt} > 0$, we need the disutility of work to be sufficiently low or production efficiency to be sufficiently high. These conditions are always satisfied in our quantitative results, so we do not consider any further the corner solution with zero traded production.

4.1 Measurement

Our measurement procedure disaggregates economic activity between traded and non-traded goods, maps economic concepts in the model to statistics in the national accounts, and gathers key statistics of government's fiscal and borrowing policies. The primary data source for macro variables is the System of National Accounts (SNA), available from the OECD. For government statistics, we additionally use data from the ECB's Interest Rate Statistics, the Greek Government's Quarterly Public Debt Bulletin (QPDB), and the World Bank's Quarterly Public Sector Debt Statistics (QPSD). Our sample period covers annual observations between 2002 and 2021.

We begin by allocating industry data on value added, compensation to employees, other taxes on production less subsidies, and hours worked between the traded and the non-traded sector. The traded sector consists of agriculture, mining, manufacturing, and transportation, and the non-traded sector consists of the remaining industries (see Appendix Table A.1). All values are divided by the price of traded goods, defined as the Paasche index of the prices of the industries that compose the traded sector. All quantities are divided by population. Hours worked include hours from both employees and the self-employed. We normalize units in the data in 2019, so that $y_{19} = p_{N19} = \ell^j_{19} = z_{i19} = 1$.

There are three deviations between aggregate economic activity in our model and aggregate economic activity recorded by the national accounts. On the production side, we do not consider taxes on production less subsidies; on the expenditure side, we do not consider investment; and on the income side, we do not consider capital income earned from domestic production. The key step that allows us to map model objects to statistics in the national accounts is to scale statistics in the national accounts by the labor share of income. Appendix A details the measurement of the labor share and how we perform these adjustments.

We split labor income between the wage and the labor input in order to estimate the productivity process. We use data on self-employed worker's hours to impute their labor income and add this income to compensation of employees from the national accounts to estimate total labor income. The unadjusted wage equals this total labor income divided by total hours, where the totals include labor income and hours of the self-employed. We then use data on labor services from KLEMS and derive the wage w adjusted for compositional changes across demographic and educational groups. Traded productivity $z_T = w$ and non-traded productivity $z_N = z_T/p_N$, where p_N is the Paasche index of the prices of the industries that compose the non-traded sector. To make sectoral productivities consistent with sectoral outputs, we define labor inputs residually as $\ell_N = p_N y_N / z_N$ and $\ell_T = y_T / z_T$.

Moving to the government sector, we trigger the sovereign debt crisis in 2011, so $\eta'_{11} = 1$ and $d_{12} = 1$. Greece regained access to international markets in 2019, so $d_{19} = 0$. For the tax rate τ, we scale government revenues from all sources with the labor share and divide the resulting revenues with output y. For transfers T, we scale with the labor share the sum of SNA item D.6 ("social contributions and benefits"), item D.39 ("other subsidies on production"), and item D.99 ("other capital transfers"). Items D.39 and D.99 include paycheck protections and similar transfers to producers and households during Covid.[19]

We calculate maturity and coupon rates of Greek debt using data on the maturity of new issuances and the residual maturity of the total debt stock from the Greek QPDB and Bloomberg. We augment these data with data on the terms of the 2012 restructuring and the time series of the stock of debt securities from 2011 to 2019 in order to better match the profile of payments after the default. For private debt during good credit standing, we find that $\lambda_p = 0.10$ and $\kappa_p = 0.05$. Official loans have a significantly longer duration than private debt, $\lambda_g = 0.04$, and a significantly lower coupon rate, $\kappa_g = 0.02$. To match the changes in private debt during the default episode, we calculate $\lambda_d = 0.07$ between 2011 and 2014 and $\lambda_d = 0.05$ between 2015 and 2018. In order to match the profile of debt service payments over the same period, we set the coupon rates to $\kappa_d = 0.05$ in 2011, $\kappa_d = 0.10$ between 2012 and 2014, and $\kappa_d = 0.03$ for years beginning in 2015. Given maturities and coupon rates, we obtain the price of debt using the formula $q_t = (\lambda_p + \kappa_p)/(\lambda_p + r + \text{spread}_t)$, where $r = 0.02$ is the risk-free rate and the spread is the difference between the interest rate on Greece's 10-year government debt and that of Germany, as recorded by the ECB Interest Rate Statistics.

We use the government budget constraint to back out the total issuance of debt and loans:

$$\text{issuance}_t = g_{Tt} + p_{Nt} g_{Nt} + T_t - \tau_t y_t + \underbrace{(\lambda_p + \kappa_p) b_t + (\lambda_g + \kappa_g) f_t}_{\text{Maturing Stocks and Interest Payments}} + \text{buyback}_t, \tag{19}$$

where all variables in the right-hand side are observed. Maturing stocks and loans data come from the ECB and government interest payments from the SNA. We also add the market value of the buyback of debt that foreign investors held in 2012 to the total issuance.

We allocate the flow of total issuance in equation (19) between revenues from issuing private debt, $q_t(b_{t+1} - (1-\lambda_p) b_t)$, and flows of official loans $\hat{\delta}_t$, using data on the maturity rates, default dates, and purchases of Greek sovereign debt by the ECB under the PEPP (see Appendix A for

[19] While the SNA explicitly advises against allocating Covid transfers to item D.99 (https://shorturl.at/CEJT3), we find that the Hellenic Statistical Authority (ELSTAT) allocates paycheck protections for self-employed to item D.99. Item D.39 increased from 3.1 billion euros in 2019 to 6.9 billion euros in 2020 and to 9.6 billion euros in 2021. Item D.99 increased from 1.5 billion euros in 2019 to 7.5 billion euros in 2020 and to 5.3 billion euros in 2021. These changes equal roughly 6 percentage points of 2019 GDP.

details). Given the allocation of issuances between debt and loans, we build the stocks of debt b and loans f from their laws of motion and the calculated maturities and price of debt.[20] Finally, we obtain private savings a_t as output minus domestic absorption, issuances of government debt and loans, and flows of debt service. The initial value of a_{02} is set so that wealth over output in 2002 matches the value of the external wealth-to-GDP ratio that is reported for Greece by the External Wealth of Nations (Lane and Milesi-Ferretti, 2018).

To summarize, our measurement process develops a dataset of variables that are internally consistent with the concepts of the model. In Appendix A, we confirm that data variables under the lens of our model align closely with variables in other datasets that one might have obtained without referring to a model. For example, we show that our time series of private debt-to-output b/y has the same level and is highly correlated with external measures of the debt-to-GDP ratio that do not need to conform to our model concepts.

Figure 4 presents the evolution of the exogenous driving forces between 2002 and 2019. In the first panel, we see that productivity in both sectors is booming until roughly 2009, falls dramatically until 2015, and then remains depressed until 2019. The second panel shows a similar pattern for government consumption, where most of government consumption is concentrated on non-traded goods. In the third panel, we see that official loans reached roughly 30 percent in 2011 and remained elevated for many years after 2011. The last panel plots the increase in the tax rate from roughly 40 percent before the crisis to 48 percent after 2011.[21]

4.2 Parameterization

We begin by specifying stochastic processes for the driving forces. The productivity process for sector $j = \{T, N\}$ is

$$\log z_{jt} = (1 - \rho_j)\bar{z}_{jt} + \rho_j \log z_{jt-1} + \epsilon^z_{jt}, \tag{20}$$

where $\bar{z}_{jt}$ is the permanent component of productivity and ϵ^z_{jt} is the innovation to the transitory component of productivity. The innovations of the two sectors are jointly normally distributed,

[20] We choose 2011 as the year of debt restructuring because 2011 is the first year without significant private debt flows. However, Greece received some official loans in 2010. Our model does not accommodate these, because the $\hat{\delta}_t$ variable becomes positive for the first time in 2011 when η_{t+1} becomes positive. To accommodate the 2010 flows of official loans, we augment the law of motion for official loans in equation (12) to $f_{t+1} = (1-\lambda_g)f_t + \hat{\delta}_t + \tilde{\delta}_t$, where $\tilde{\delta}_t$ is another flow of official loans that allows us to model the 2010 loans. We assume that $\tilde{\delta}_t$ is realized at the beginning of the period, before the government and the private sector make their decisions, that $\tilde{\delta}_t$ is independent over time, and that a positive value of $\tilde{\delta}_t$ is unexpectedly realized in 2010. In the third panel of Figure 4, we plot the sum of both flows, $\hat{\delta}_t + \tilde{\delta}_t$.

[21] Our average tax rate in the sample is 0.45, which is equal to the average combined tax wedge from consumption and labor income taxes calculated for Greece by Chodorow-Reich, Karabarbounis, and Kekre (2023). The authors use a more elaborate procedure to calculate tax rates, because they have investment and capital in their model. The correlation between our series and theirs is 0.94.

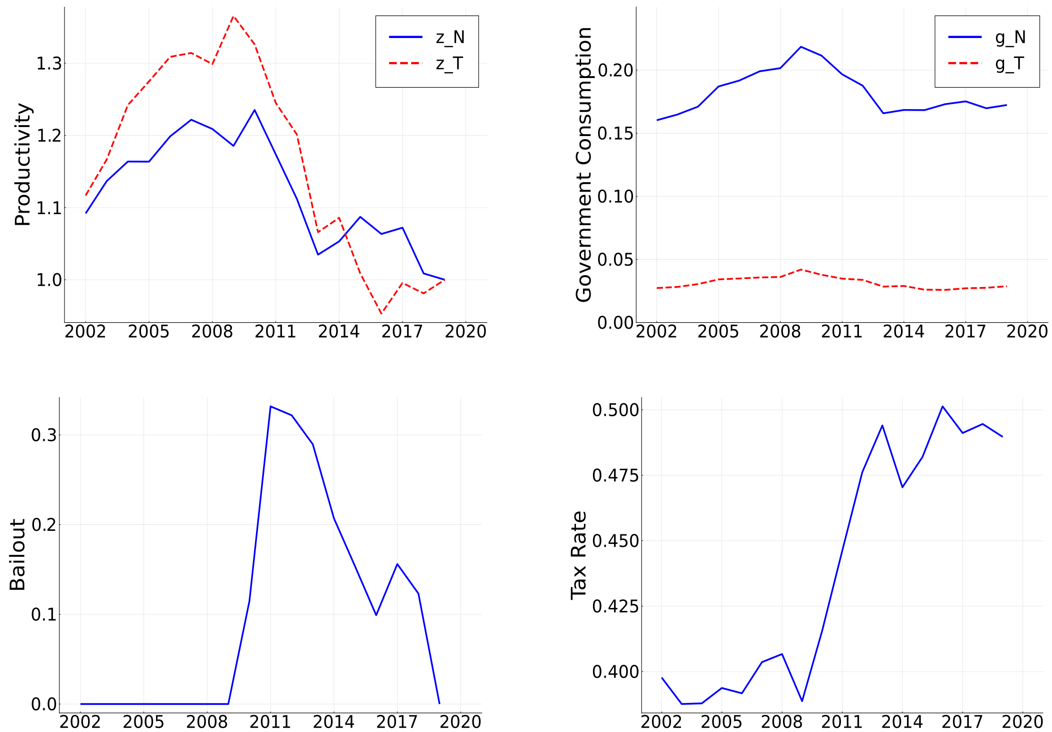


Figure 4: Exogenous Driving Processes

$\epsilon_t^z \sim N(0, \Sigma_z)$. We assume that households, the government, and foreigners always anticipate a constant permanent component, $\mathbb{E}\bar{z}_{jt} = \bar{z}_{jt-1}$, but that in 2011 there is a one-time unanticipated change in the permanent component.

The top panel of Table 1 shows our estimates of the parameters of the productivity processes. The processes are relatively persistent, with autoregressive coefficients of $\rho_N = 0.86$ and $\rho_T = 0.84$. As evidenced in the first panel of Figure 4, mean productivity falls dramatically after 2010. These drops lead us to estimate one-time, unanticipated changes in the permanent component of productivity $\beta^{11}_{\bar{z}_N} = -0.29$ for the non-traded sector and $\beta^{11}_{\bar{z}_T} = -0.42$ for the traded sector. The innovations to productivity have a correlation of $\sigma_{z_N z_T} = 0.45$.[22]

To economize on state variables for the computation of the model, we specify government consumption as a function of productivities:

$$\log g_{jt} = \bar{g}_{jt} + \beta_{g_j N} \log z_{Nt} + \beta_{g_j T} \log z_{Tt} + \beta_{g_j NT} \log z_{Nt} \log z_{Tt} + \epsilon^g_{jt}, \quad \epsilon^g_{jt} \sim N(0, \sigma^2_{g_j}), \qquad (21)$$

where $\bar{g}_{jt}$ is the permanent component of government consumption and $\epsilon^g_{jt} \sim N(0, \sigma^2_{g_j})$ is the innovation to the transitory component of government consumption. As we did for productivity,

[22]For each sector $j = \{T, N\}$, we run the regression $\log z_{jt} = (1-\rho_j)\bar{z}_{jt} + (1-\rho_j)\beta^{11}_{\bar{z}_j}\mathbb{I}(t \geq 2011) + \rho_j \log z_{jt-1} + \epsilon^z_{jt}$, where $\mathbb{I}(t \geq 2011)$ is a dummy variable indicating the regime after 2011. We estimate elements of the Σ_z matrix using the in-sample variances and covariances of the residuals of these regressions.

Table 1: Parameter Values: Stochastic Processes

	Parameter	Value	Parameter	Value	Parameter	Value
Productivity	ρ_N	0.86	ρ_T	0.84	$\bar{z}_N$	0.23
	$\bar{z}_T$	0.32	$\beta^{11}_{\bar{z}_N}$	-0.29	$\beta^{11}_{\bar{z}_T}$	-0.42
	σ_{z_N}	0.03	σ_{z_T}	0.04	$\sigma_{z_N z_T}$	0.45
Government	$\beta_{g_N N}$	0.95	$\beta_{g_N T}$	0.34	$\beta_{g_T N}$	-0.05
	$\beta_{g_T T}$	1.34	$\beta_{g_N NT}$	1.72	$\beta_{g_T NT}$	1.72
	σ_{g_N}	0.04	σ_{g_T}	0.04	$\bar{g}_N$	-1.98
	$\bar{g}_T$	-3.77	$\beta^{11}_{\bar{g}_N}$	0.15	$\beta^{11}_{\bar{g}_T}$	0.15
	$\beta^{20}_{\bar{g}_N}$	0.10	$\beta^{20}_{\bar{g}_T}$	0.10		
Taxes	τ_L	0.40	τ_H	0.48		
Official Flows	δ_L	0.35	δ_H	0.65	π_δ	0.25
Lockdowns	π_ℓ	0.50				

Table 2: Parameter Values: Without Solving the Model

Parameter	Value	Explanation
ω_c	0.30	expenditure share of traded goods, private sector
ω_g	0.14	expenditure share of traded goods, government
ϕ	0.44	substitution elasticity, private, traded and non-traded goods
γ	0.40	share of optimizing households
r	0.02	risk-free rate
κ_p	0.04	coupon rate, government debt in good credit standing
λ_p	0.10	maturity rate, government debt in good credit standing
$\kappa_d(.)$	$[0.03, 0.10]$	coupon rate, government debt in bad credit standing
$\lambda_d(.)$	$[0.05, 0.07]$	maturity rate, government debt in bad credit standing
κ_g	0.02	coupon rate, government loans
λ_g	0.04	maturity rate, government loans
$\bar{\eta}$	0.47	haircut on government debt
ψ	0.14	reentry probability
$\bar{d}$	0.80	issuance cost parameter
ν_1	0.00	taste shock parameter
ν_2	0.25	taste shock parameter

we assume that households, the government, and foreigners always anticipate a constant permanent component, $\mathbb{E}\bar{g}_{jt} = \bar{g}_{jt-1}$. We introduce unanticipated changes in the permanent component of government consumption in 2011 and during Covid, because government consumption is a function of productivity. The middle panel of Table 1 summarizes our estimates.[23]

The tax rate takes two values, $\tau_t \in \{\tau_L, \tau_H\}$. The perceived tax rate process is $\mathbb{E}\tau_t = \tau_{t-1}$, so that households, the government, and foreigners always expect the tax rate to equal its value in the previous year. We introduce a one-time, unanticipated change in the tax rate in 2011, consistent with the significant increase in the tax rate shown in Figure 4. The third panel of Table 1 shows our estimates of $\tau_L = 0.40$ for the period before 2011 and $\tau_H = 0.48$ for the period after 2011.

Next, we specify the variables that characterize flows of official loans: δ, which is announced at the beginning of the period, and $\hat{\delta}$, which is realized after the government makes its decisions. We specify these variables as multiples of the government's spending on goods and debt service, $\delta_g\,[g_T + p_N g_N + (\lambda_k + \kappa_k)b + (\lambda_g + \kappa_g)f]$ for $k \in \{p, d\}$. The multiple δ_g takes three values, $\delta_g = \{0, \delta_L, \delta_H\}$. The second-to-last panel of Table 1 shows our estimates of $\delta_L = 0.35$ and $\delta_H = 0.65$. We feed into the model $\delta_g = \delta_H$ between 2011 and 2014 and $\delta_g = \delta_L$ between 2015 and 2018.

The variables characterizing the flows of official loans are linked through two transition matrices. The first transition matrix maps the multiple at beginning of the period (the δ_g of δ) to the multiple realized after the government makes its decision (the δ_g of $\hat{\delta}$). With some abuse of notation,

$$\hat{\delta}|(\delta, \eta' = \bar{\eta}) = \begin{bmatrix} 1-\pi_{\hat{\delta}} & \pi_{\hat{\delta}}/2 & \pi_{\hat{\delta}}/2 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \quad \hat{\delta}|(\delta, \eta' = 0) = 1. \tag{22}$$

The first row of the transition matrix says that when the government begins the period with a multiple of zero for δ and chooses to restructure its debt ($\eta' = \bar{\eta}$), with probability $1 - \pi_{\hat{\delta}}$ it transitions to a $\hat{\delta}$ of zero, and with equal probability $\pi_{\hat{\delta}}/2$ it transitions to a $\hat{\delta}$ characterized by either a low multiple δ_L or a high multiple δ_H. The parameter $\pi_{\hat{\delta}}$ governs the moral hazard induced by the possibility of bailouts, because starting from good credit standing the government places a higher probability of receiving a loan when $\pi_{\hat{\delta}}$ is higher. We estimate $\pi_{\hat{\delta}}$

[23]For every sector $j = \{T, N\}$, we run regression (21) and add a time dummy that indicates the regime between 2011 and 2019 and another time dummy that indicates the regime between 2020 and 2021. The estimated coefficients on these dummies are $\beta^{11}_{\bar{g}_j}$ and $\beta^{20}_{\bar{g}_j}$. We estimate $\sigma^2_{g_j}$ using the in-sample variances of the residuals of these regressions. Innovations to the transitory components of government consumption are uncorrelated across sectors, because government consumptions are correlated through their dependence on sectoral productivities.

jointly with other parameters when we solve the model. The second and third rows of the transition matrix show that, starting from a low or high multiple always leads to the same low or high multiple when the government restructures its debt ($\eta' = \bar{\eta}$). Similarly, when the government does not restructure its debt ($\eta' = 0$), official loans always remain in the same multiple, $\hat{\delta}|(\delta, \eta' = 0) = 1$.

The second transition matrix specifies how the realized values of official loans $\hat{\delta}$ transits to next period's announced loans δ':

$$\delta'|\hat{\delta} = \begin{bmatrix} 1 & 0 & 0 \\ \pi_\delta & 1-\pi_\delta & 0 \\ 0 & \pi_\delta & 1-\pi_\delta \end{bmatrix}. \tag{23}$$

In the first row, starting with a zero realized multiple for official loans always leads to a zero multiple at the beginning of the next period. The parameter π_δ governs the transience of official loans, because it equals the probability that the multiple decreases by one step starting from a positive multiple. In the second-to-last panel of Table 1, we estimate this probability to be $\pi_\delta = 0.25$, so that official loans are quite persistent over time. Our estimate reflects the evolution of official loans in the third panel of Figure 4, which shows that Greece received loans for most years in the 2010s.

Table 2 reports values of parameters that we set before solving the model. We set the weight parameters in the consumption aggregators to match expenditure shares of traded goods: $\omega_c = 0.30$ for households and $\omega_g = 0.14$ for the government. We follow Stockman and Tesar (1995) and set the elasticity of substitution between traded and non-traded goods to $\phi = 0.44$. We set the fraction of optimizing households to $\gamma = 0.40$, close to the value that Martin and Philippon (2017) estimate for Greece in their study of the boom-bust cycle in the eurozone. The risk-free rate on private savings is $r = 0.02$. We calculate maturity and coupon rates for government debt using data from the ECB and the Greek QPDB as described before in our measurement section. Using the Greek sovereign debt crisis, we calculate a haircut rate $\bar{\eta} = 0.47$ and a reentry probability $\psi = 0.14$.

Table 3 presents values of the remaining parameters. The first panel displays parameters estimated with data between 2002 and 2019, before Covid. We estimate these parameters by requiring that endogenous variables of the model match their analogs in the data along certain dimensions (see Appendix B for details on the process). Parameters affect all model variables simultaneously, but here we informally discuss features of the data that most intuitively identify the parameters. In the first column, the production efficiency parameters θ^o, θ^h are estimated so that the model matches the inequality in pre-tax-and-transfer Greek income reported by

Table 3: Parameter Values: Solving the Model

	Value	Explanation		Value	Explanation
θ^o	1.79	productivity, o	β_c	0.97	discount factor, households
θ^h	0.36	productivity, h	β_g	0.96	discount factor, government
χ^o	0.84	disutility, o	μ	0.05	cost of default, constant
χ^h	0.46	disutility, h	μ_N	0.11	cost of default, slope in $log(z_N)$
σ	1.16	risk aversion	μ_T	0.09	cost of default, slope in $log(z_T)$
ε	0.56	Frisch elasticity	ζ	0.24	government weight on o
ξ	0.87	progressivity of transfers	α	0.90	complementarity (g, c)
			$\pi_{\hat{\delta}}$	0.74	moral hazard
$\bar{c}_N$	0.71	Covid constraint, consumption	$\bar{\ell}$	0.66	Covid constraint, labor

the Luxembourg Income Study. In order to match data on inequality in post-tax-and-transfers income reported by the Luxembourg Income Study, our model requires a progressivity of transfers parameter $\xi = 0.87$.[24] The disutilities of labor are chosen to normalize labor supply of both types of households to one in 2019. We find that the model does a good job in terms of accounting for the time series of output, labor supply, and consumption, with a coefficient of relative risk aversion $\sigma = 1.16$ and a Frisch elasticity of labor supply $\varepsilon = 0.56$. These values fall comfortably in the range of values used in dynamic general equilibrium models and models of sovereign debt.

Moving to the second column, we estimate the discount factor of households so that households discount at a rate which is lower than the risk-free rate, $\beta_c = 0.97$. This allows the model to match the decline in private savings a during the boom of the 2000s. The government is slightly more impatient than households, with a discount factor of $\beta_g = 0.96$. This discount factor is a key determinant of the speed of sovereign debt accumulation. Our estimate of β_g differs from much of the sovereign default literature in that we do not require a high degree of impatience for the government, partly because the unusually large fluctuations in productivity generate a significant sovereign spread during the crisis. The constant in the default cost function μ controls the amount of sustainable debt at the average values of productivity. We find that default costs are substantial and that they increase with productivity, so that parameters μ_N and μ_T are positive. The high cost of default allows the model to sustain a high

[24] In the Luxembourg Income Study, we observe that pre-tax-and-transfer income per capita at the top 40 percent of the distribution is roughly 5 times the pre-tax-and-transfer income per capita at the bottom 60 percent of the distribution. The ratio of disposable income, which we equate with the ratio of post-tax-and-transfer income, is around 2.5.

debt-to-GDP ratio.[25]

The government places a lower weight $\zeta = 0.24$ on the welfare of the optimizing households relative to their share $\gamma = 0.4$ in the population. This feature of the model allows it to generate the high level of transfers that we observe in the data. The complementarity between private and government consumption, $\alpha = 0.90$, allows the model to generate an increasing path of both government borrowing and transfers during the boom of the 2000s, because the government transfers more resources to households to increase their consumption when government consumption is high. Finally, the relatively high value of the moral hazard parameter, $\pi_{\hat{\delta}} = 0.74$, also allows the model to sustain high levels of government debt, because the government expects a disbursal of loans in case of default with high probability.

4.3 Time Series of Model Outcomes

Figure 5 compares time series of the endogenous variables generated by the model with their analogs in the data. We focus on the period between 2002 and 2019 and discuss the Covid period when we introduce our extended model. To generate these time series, we feed into the model's policy functions the paths of productivity, government consumption, tax rate, and official loans displayed previously in Figure 4 (see Appendix C for more details).

In the first panel, we see that the model does a good job of matching the boom in output in the 2000s. The model matches almost exactly the more than 30 log points decline in output between the late 2000s and 2016. After 2016, the model generates around half of the output recovery. The dynamics of output follow closely the dynamics of productivity and government spending, as discussed previously in Figure 4.[26] Deviations of output in the data from output in the model arise because of variations in labor supply. Since these deviations are generally small, we conclude that labor supply in the model behaves quite reasonably over the sample period.

In the second panel, we see that the model also does a good job of matching the consumption boom in the 2000s and the dramatic decline in the first part of the 2010s. Further, as the next two panels show, the model is generally consistent with the observed sectoral comovement of consumption. The model's success in matching the consumption dynamics is also reflected in

[25] To get a sense of magnitudes, from the perspective of the government the utility cost of default is equivalent to a one-time consumption drop between 55 and 80 percent, depending on the state of the economy, for both types of households. Converting this to a annualized flow using the government's discount factor, yields a permanent consumption loss between 2 and 3 percent.

[26] We acknowledge that productivity may be responding to more primitive shocks. For instance, Chodorow-Reich, Karabarbounis, and Kekre (2023) demonstrate how tax, foreign demand, and financial shocks reduced utilization during the Greek bust.

Figure 5: Time Series of Endogenous Variables

the path of private assets in the fifth panel. Private assets decline substantially in the boom, because impatient optimizing households deaccumulate assets. Private assets recover in the early part of the 2010s, because transfers from government increase or remain high and these transfers are perceived by optimizing households as transitory. The model and the data differ with respect to the magnitude of the recovery of assets, with the model accounting for only about half of the recovery of assets.

In terms of fiscal policy, the model matches closely the level of sovereign debt. It also matches the rise of debt during the boom period. The model is generally successful in accounting for the dynamics of transfers, with transfers rising during the boom period, peaking around the height of the crisis, and then falling precipitously as the economy goes into the recession.

The model generates a restructuring decision for the government in 2011.[27] Additionally, the model successfully accounts for the time series of the spread.[28] It accounts for the low spread before 2009, the spike of the spread between 2010 and 2012, and the decline in the spread after the restructuring. With respect to the spread, the two most important deviations of the model from the data are in 2012 and in 2015. However, as we show in Appendix A, these deviations may be attributable to a rise in the risk premium that we did not model. Subtracting our estimate of the risk premium in 2012 allows the model to match the data almost exactly in terms of the spread. The risk premium plausibly increased in 2015, following political uncertainty and the referendum on exiting the euro. However, these specific events are not relevant for the parameters of the model that matter for the counterfactuals during Covid, because Greece had a stable government in this period.

Before discussing the Covid period, we pause to contrast our quantitative strategy to alternatives in the sovereign default literature. The most common approach is to choose parameters such that moments from a long-run simulation of the model match their data counterparts (see, for example, Chatterjee and Eyigungor, 2012). Another common approach is to produce similar long-run simulations, extract some number of years leading to a default, and then require that moments calculated using those samples match their data counterparts (see, for example, Arellano, 2008). These approaches are not appropriate for Greece, because Greece's experience

[27] We add taste shocks to the government's problem in equation (13) to compute in a robust way the model's solution (see Appendix B for details). We classify a year as a year with restructuring when there is a larger than 50 percent probability that the government restructures across the different realizations of the taste shocks.

[28] The spread is calculated with the standard convention, $\text{spread}_t = \frac{\lambda_p + \kappa_p}{q_t} - \lambda_p - r$, where r is the risk-free rate, κ_p is the coupon rate, λ_p is the maturity rate, and q_t is the price of debt in equation (18). In 2010, the spread is calculated using the price q_t after the change to the regime with lower productivity and higher taxes. In 2011, the spread is calculated after default, but before the flow of official loans $\hat{\delta}_t$ is realized. In 2012, the spread is calculated before the haircut $\bar{\eta}$ on debt is applied. See Appendix C for more details.

from 2002 to 2019 is a outlier relative to other default episodes on both macroeconomic and government borrowing dimensions. While the unique nature of the crisis makes it a very informative sample to estimate key model parameters, this uniqueness also means that long-run average outcomes are not the appropriate model analogue for the 18 years of data. Following the standard practice, we show in Appendix Table A.3 that the long-run model moments under our parameterization deviate in important dimensions from averaged sample moments.

5 The Covid Period

We begin by extending the model to consider the economic impacts of lockdowns during the Covid period. We demonstrate the success of the model in accounting for salient observations on the dynamics of macro variables, external borrowing, and the spread during the Covid recession. Finally, we perform various counterfactuals to assess the economic forces that determine the spread and other macroeconomic outcomes.

5.1 Extension of the Model during Covid

The economic environment during the Covid period is the same as the one in the period before Covid, except for the lockdowns. We model lockdowns using two constraints. The first constraint applies to the consumption of non-traded goods:

$$\mathbb{I}(\text{lock}_t = 1)\left(c_{Nt} - \bar{c}_N\right) \leq 0, \tag{24}$$

where $\bar{c}_N$ is a parameter that governs the tightness of the constraint and lock_t is an exogenous variable that takes the value of one during lockdowns. We motivate constraints on consumption of non-traded goods with the observation that lockdowns affected mostly service industries, such as accommodation, education, and entertainment, while stay-at-home orders did not prevent households from consuming traded goods, such as those produced by agriculture and manufacturing, to such a large extent.

The second constraint applies to the labor supply of the hand-to-mouth households:

$$\mathbb{I}(\text{lock}_t = 1)\left(\ell_t^h - \bar{\ell}\right) \leq 0, \tag{25}$$

where $\bar{\ell}$ is a parameter that governs the tightness of the constraint. We motivate this constraint with the observation that higher-income households mostly retained their jobs because they could be performed from home, while lower-income households faced significant earning losses because jobs in the service sector could not be performed as easily from home.

Our modeling of lockdowns is consistent with previous narratives of the economic impacts of the pandemic. For instance, Stantcheva (2022) summarizes results from multiple research teams and countries that show the disproportionate impact of lockdowns on non-traded sectors which were deemed non-essential and had more difficulty substituting from in-person to online transactions. Lockdowns also had a disproportionate impact on lower-income households, which had fewer opportunities for remote work and experienced a significantly larger probability of job loss.

The last panel of Table 3 shows the values of the two constants that parameterize the constraints. We pick $\bar{c}_N$ and $\bar{\ell}$ such that the model matches the decline in output and non-traded consumption in 2020 relative to 2019. The perceived persistence of lockdowns is

$$\pi_\ell = \text{Prob}(\text{lock}_{t+1} = 1 | \text{lock}_t = 1) = 0.5, \qquad \text{Prob}(\text{lock}_{t+1} = 0 | \text{lock}_t = 0) = 1. \tag{26}$$

We set the persistence π_ℓ to 0.5, which implies a two-year expected duration of lockdowns. The duration is two years based on some scenarios considered by the International Monetary Fund (2020) that projected potential lockdowns also in 2021. This parameter turns out to be crucial in understanding the behavior of the spread during Covid, and thus we discuss other parameterizations in our counterfactuals. Once lockdowns are lifted, everyone expects lockdowns to be lifted forever.

Finally, we augment the process for official loans in equation (23) to model ECB's purchases of sovereign debt under the PEPP. In equation (27), the ECB extends loans to the government at the beginning of the period in the first year of lockdowns without being prompted by debt restructuring,

$$\delta_t | (\hat{\delta}_{t-1}, \text{lock}_t = 1, \text{lock}_{t-1} = 0) = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 1 & 0 \\ 0 & \pi_\delta & 1 - \pi_\delta \end{bmatrix}. \tag{27}$$

When $\text{lock}_{t-1} = 1$ or $\text{lock}_t = 0$, the beginning of the period loans δ follow the process in equation (23). The realized loans $\hat{\delta}$ after the government makes its debt restructuring decision follow the process in equation (22).[29]

[29] In the stock of official loans f, we model identically both the loans that were extended to Greece in the 2010s under the economic assistance programs and the ECB's purchases of Greek sovereign debt in secondary markets after 2020 through the PEPP. Appendix B shows the equivalence of loans and purchases of sovereign debt under the PEPP when the government realizes that profits from bond purchases are rebated.

Table 4: Performance of Model during Covid

Year	Statistic ($\times 100$)	Data	Model, $\bar{\ell}, \bar{c}_N$	Model, $\bar{\ell}$	Model, $\bar{c}_N$
2020	$\log y_{20} - \log y_{19}$	−8.1	−8.1	−6.9	1.3
	$\log c_{20} - \log c_{19}$	−4.1	−10.5	2.4	−8.9
	$(b_{21} - b_{20})/y_{19}$	12.0	12.0	12.3	3.0
	$(T_{20} - T_{19})/y_{19}$	6.1	9.0	10.0	3.6
	$(a_{21} - a_{20})/y_{19}$	4.4	3.9	−5.2	1.9
	$\text{spread}_{20} - \text{spread}_{19}$	0.1	0.4	0.4	0.0
2021	$\log y_{21} - \log y_{19}$	−4.0	−2.9	−2.2	−3.3
	$\log c_{21} - \log c_{19}$	1.4	2.7	1.8	3.5
	$(b_{22} - b_{20})/y_{19}$	21.0	17.3	17.6	9.7
	$(T_{21} - T_{19})/y_{19}$	5.5	3.7	4.0	5.2
	$(a_{22} - a_{20})/y_{19}$	5.4	−5.8	−13.8	−7.4
	$\text{spread}_{21} - \text{spread}_{19}$	0.0	0.0	0.0	0.0

5.2 Performance of the Model during Covid

We introduce lockdowns unexpectedly in 2020. We choose to introduce lockdowns only in 2020 because Greece lifted the lockdowns before the middle of 2021, and we discuss below the case in which lockdowns extend to 2021. We solve for the endogenous variables of the model using the calibrated values of $\bar{c}_N$, $\bar{\ell}$, and π_ℓ. The results of this exercise are disciplined by keeping all other parameters constant at their values shown in Tables 1, 2, and 3. These parameter values were informed only by observations through 2019.[30]

Table 4 presents changes in key variables in 2020 relative to 2019 (first panel) and in 2021 relative to 2019 (second panel). The first column presents statistics in the data and the second column presents the corresponding statistics in the model when we introduce both the constraint on labor supply $\bar{\ell}$ and the constraint on non-traded consumption $\bar{c}_N$. The only statistics targeted during our calibration are the changes in output and non-traded consumption between 2019 and 2020.[31]

The model matches almost perfectly the increase in government debt in both 2020 and

[30] We start the model from the state variables (a, b, f) observed in the data at the beginning of 2020. We proceed similarly to our analysis of the period before Covid and feed in productivity and government consumption shocks during Covid. Productivities increase somewhat in 2020 relative to 2019, but in 2021 they revert back to their 2019 values. Government consumption increases substantially in 2020 and 2021. However, these shocks tend to stimulate economic activity, and so we focus our discussion on the effects of lockdowns.

[31] We define consumption expenditure in terms of traded goods similarly to output, $c \equiv c_T + p_N c_N$, where $c_i = \gamma c_i^o + (1-\gamma) c_i^h$ for each sector $i = \{T, N\}$.

2021. Further, it matches closely the increase in transfers in 2020 and 2021 and the increase in private savings in 2020. Finally, the model is successful in accounting for the stability of the sovereign spread. In 2020, the spread increases by 0.1 percentage point in the data, whereas in the model it increases by 0.4 percentage point. As argued in Section 2, these are small changes when compared with the historical changes in spreads during high government borrowing and recessions. The model matches perfectly the stability of the spread in 2021 relative to 2019.[32]

The economics of lockdowns are that the government borrows substantially in order to transfer resources to hand-to-mouth households, which, because of the constraint on their labor supply, suffer a sharp drop in their labor income that they cannot smooth. However, some of the transfers spill over to the optimizing households. Optimizing households also face a constraint on non-traded consumption and realize that increased transfers are transitory, so they save the extra resources. When lockdowns are lifted in 2021, optimizing households reduce their savings and begin to consume significantly more. The government keeps transfers elevated because it is impatient and the ECB purchases under PEPP increase its fiscal space. The consumption boom of optimizing households and expansionary fiscal policy drive a faster recovery of consumption relative to the recovery of output. Indeed, as Table 4 shows both for the data and for the model, output is still depressed in 2021 relative to 2019, whereas consumption is higher in 2021 than in 2019.

The last two columns of the table present model statistics when we introduce separately the constraint on labor supply $\bar{\ell}$ or the constraint on non-traded consumption $\bar{c}_N$. The model with the constraint on labor supply generates almost the entire drop in output, but misses the drop in consumption. Conversely, the model with the constraint on non-traded consumption generates almost the entire drop in consumption, but misses the drop in output. For the behavior of government debt and transfers, the constraint on labor supply is the crucial constraint. In that model, the government borrows substantially to transfer resources to hand-to-mouth households, which are the only households hit by the labor supply constraint. On the other hand, in the model with only a constraint on non-traded consumption, the government does not borrow as much, because hand-to-mouth households and optimizing households are equally affected by lockdowns.

These results offer insights into the debate about the nature of the Covid shock. Most

[32]The spread calculation in the data is somewhat sensitive to the 2019 value, because 2019 is the year in which Greece reenters the market and the spread falls by more than 2 percentage points between the beginning of the year and the end of the year. For this reason, we use the spread at the end of 2019 as the baseline value of the spread before the Covid recession, and we difference out the spreads in 2020 and 2021 relative to this 2019 spread.

of the literature has focused on disentangling demand versus supply origins of the recession using closed-economy frameworks (Baqaee and Farhi, 2022; Guerrieri, Lorenzoni, Straub, and Werning, 2022). In an open economy, however, consumption is potentially disconnected from production because households and the government can trade in international markets to finance their expenditures. Although constraints on both demand and supply are important for the drop in macroeconomic aggregates, we find that constraints on supply are more important in terms of understanding the fiscal policy responses following the lockdowns. The difference between the two types of constraints is that demand constraints do not increase the value of providing transfers as much as constraints on the supply side do in the open economy.

5.3 Counterfactuals during Covid

We are now ready to answer the question that motivated this paper. We developed a model that generates a significant increase in government borrowing alongside a significant recession in 2020. Yet, spreads remain relatively constant. The behavior of government debt and spread during the Covid recession contrasts sharply with their behavior in other time periods. So, why was this case during Covid, despite a significant recession and accommodative fiscal policies?

Table 5 performs a series of counterfactual exercises to assess the economic forces affecting spreads and other macroeconomic outcomes. The first panel of the table presents the changes in output, consumption, debt, transfers, relative consumption, and spreads in 2020 in the data and the model. Each row in the other panels presents a different counterfactual in which we change values of certain parameters or shut off mechanisms. The entries display changes in model variables under the counterfactual relative to the baseline model. For example, the first entry says that in the absence of ECB's policies during Covid, output would have been 0.6 percentage point higher than in the baseline model, which features these policies. Thus, output would have declined by 7.5 percent in the counterfactual instead of 8.1 percent in the baseline.

5.3.1 Pandemic Emergency Purchases

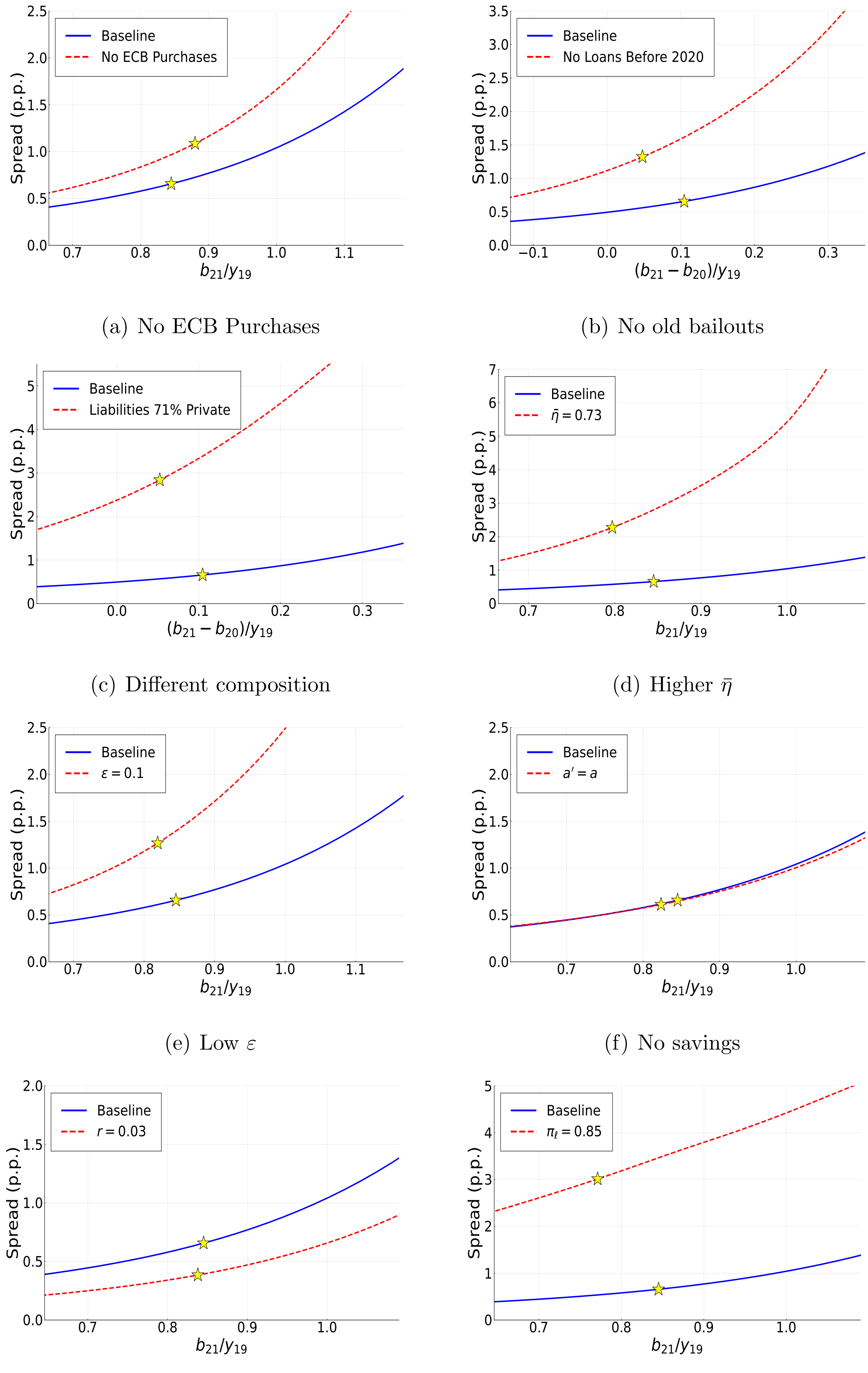
The first row assesses the role of the PEPP, under which the ECB purchased sovereign debt equal to 10 percent of output in both 2020 and 2021. We find that these purchases allowed the Greek government to fund substantially more transfers than it would have otherwise. Increased transfers lowered inequality substantially, as, in the absence of increased transfers, the consumption of optimizing households would have increased by almost 17 percentage points more than the consumption of hand-to-mouth households. Despite the importance of ECB purchases for increasing transfers, spreads would have increased by only 0.5 percentage point

Table 5: Counterfactuals

		(100 × Δ log)					(Δ p.p.)
		y	c	b	T	c^o/c^h	Spread
	(relative to 2019 values)						
	Data 2020	−8.1	−4.1	12.0	6.1		0.1
	Model 2020	−8.1	−10.5	12.0	9.0	−19.5	0.4
	(relative to 2020 model)						
1.	$\hat{\delta}_{t\geq 20} = 0$	0.6	−6.3	3.5	−7.3	16.6	0.5
2.	$\pi_{\hat{\delta}} = 0.9$	0.0	0.1	0.2	0.2	−0.3	0.0
3.	$\pi_{\hat{\delta}} = 0.1$	0.1	−0.4	−0.7	−0.5	1.0	−0.2
4.	$\lambda_p = 0.04$	−0.1	−0.3	2.5	−0.4	0.8	0.4
5.	$\hat{\delta}_{t<20} = 0$	−0.5	−1.0	−5.8	−1.4	3.3	0.7
6.	$\bar{q}b^{\text{new}} = 0.71(\bar{q}b + f)$	−0.1	−5.2	−5.5	−6.2	14.1	2.3
7.	$\bar{\eta} = 0.73$	0.4	−6.2	−4.7	−7.3	16.5	1.8
8.	$\bar{\eta} = 0.22$	−1.0	7.1	6.9	8.8	−16.7	−0.6
9.	$\varepsilon = 0.1$	0.0	−1.4	−2.6	−3.9	31.9	0.7
10.	$a' = a$	−3.7	−2.5	−2.2	−4.1	10.4	0.0
11.	$r = 0.03$	2.7	−1.2	−0.7	−0.7	0.6	−0.3
12.	$\pi_\ell = 0.85$	0.1	−8.8	−7.1	−10.3	24.6	2.4
13.	persistent z shocks	0.1	13.0	−3.7	−3.6	14.9	−0.4
14.	permanent z shocks	0.1	9.5	−6.0	−6.6	18.0	−0.2
15.	$\hat{\delta}_{t<20} = 0, \hat{\delta}_{t\geq 20} = 0$	0.0	−8.5	−2.9	−10.1	24.1	1.9
16.	$\pi_\ell = 0.85, \hat{\delta}_{t\geq 20} = 0$	0.5	−15.3	−0.6	−17.3	45.4	5.1
	(relative to 2021 model)						
17.	$\text{lock}_{21} = 1$	−9.6	−16.2	6.6	1.7	−7.1	1.0
18.	$\text{lock}_{21} = 1, \pi_\ell = 0.85$	−9.2	−22.1	−3.9	−5.0	9.8	3.7
19.	$\text{lock}_{21} = 1, \pi_\ell = 0.85, \hat{\delta}_{t\geq 20} = 0$	−8.5	−32.4	−1.0	−15.8	44.6	12.9

in the absence of the purchases.

To understand this result, panel (a) of Figure 6 presents the relationship between the spread and the debt issuance. The blue solid curve presents the menu of spreads and debt issuance that the government faces under the baseline model. The spread is increasing in debt issuance, because issuing more debt moves the economy closer to the restructuring region and the price of debt q in equation (18) falls. The star in the blue solid curve indicates the optimal choice of the government among all combinations of spreads and borrowing. Removing the ECB purchases shifts the menu of spreads and debt issuances upward to the red dashed curve. If debt issuance



(a) No ECB Purchases

(b) No old bailouts

(c) Different composition

(d) Higher $\bar{\eta}$

(e) Low ε

(f) No savings

(g) Higher r

(h) Higher π_ℓ

Figure 6: Menu of Spreads and Debt Issuance

is held constant, removing the ECB purchases would increase the spread. The flatness of the curve around the optimal choice of the government determines how much of the equilibrium adjustment is borne by either spreads or debt issuance. To offset the lower purchases from the ECB, the government is willing to borrow 3.5 more percentage points of output from private investors by paying a spread that is 0.5 percentage point higher than that in the baseline model with the purchases. But the government does not borrow enough to compensate for the entire loss of purchases, because doing so would move the economy to the steeper part of the spread function. Had the Greek government borrowed an additional 7 percentage points to offset the missing PEPP resources, the spread would have increased by around 0.9 percentage point in our model relative to the baseline.

How do our model estimates of the effects of the ECB's sovereign debt purchases compare with empirical estimates? The model predicts an increase in the spread by 0.5 percentage point in 2020 in the absence of the purchases by the ECB. Without the loans in the 2010s, the model generates a roughly 2 to 2.5 percentage points increase in the spread between 2012 and 2018. Trebesch and Zettelmeyer (2018) examine how ECB purchases under the Securities Market Program affected the cross-section of Greek bond yields in 2010. In comparing their estimates with ours, we note that their effects may incorporate channels other than reductions in default probability and that ECB purchases were concentrated on lower-maturity and higher-yield bonds. The authors estimate that ECB purchases reduced the yield of the purchased bonds by between 0.8 percentage point and 1.9 percentage points and that the drop in yields did not spill over to non-targeted bonds. Combining an event-study with a Bayesian VAR methodology between 2013 and 2020, Rostagno, Altavilla, Carboni, Lemke, Motto, and Saint-Guilhem (2021) estimate that the ECB's Asset Purchase Program (APP) before the Covid period reduced 10-year yields of Germany, France, Spain, and Italy by around 0.5 percentage point in 2014. They also estimate that the incremental effect of the Pandemic Emergency Purchase Program was roughly 0.5 percentage point, which is identical to our model-based estimate. According to the authors, the cumulative effect of all quantitative easing interventions on the four country yields was around 2 percentage points, which is consistent with our estimate of the cumulative effects of the 2010s loans on the Greek spread.

5.3.2 Moral Hazard and Maturity Length

The second and third rows of the second panel of Table 5 assess how changes in the level of moral hazard might have prevented spreads from rising. In our baseline calibration, the probability of receiving a bailout is $\pi_{\hat{\delta}} = 0.74$. Increasing the probability to 0.9 produces negligible changes on all variables. Lowering the probability to 0.1 decreases the spread slightly. The effects of changing the parameter $\pi_{\hat{\delta}}$ are small because bailouts affect outcomes only when the government chooses to restructure, and restructuring happens in less than 1 percent of years in the long-run equilibrium of our model.

Did spreads remain low because of changes in the maturity structure of debt? Recall that in our baseline parameterization we have $\lambda_p = 0.10$, which implies an average maturity of 10 years. In row 4 of the table, we lengthen the maturity of private debt to 25 years to match the maturity of official loans. Lengthening the maturity increases the spread by 0.4 percentage point, because the government has increased incentive to dilute the debt and foreign investors perceive it as more risky. Conversely, shortening the maturity of debt would have lowered the spread. To the extent that policy interventions allowed Greece to borrow at maturities longer than the ones it would have existed without these interventions, we conclude that lengthening maturities do not explain the puzzle of the missing spread.

5.3.3 Old Bailouts

The next rows of Table 5 quantify the role of the bailouts that Greece received between 2010 to 2018. In row 5, labelled $\hat{\delta}_{t<20} = 0$, we remove the entire history of bailouts in the 2010s and begin the model in 2020 with only private debt and no official loans. In this case, the spread increases by 0.7 percentage point more than in the baseline, which exceeds the effect of the PEPP on the spread. Unlike removing the PEPP purchases, removing the old loans causes the government to cut back significantly on borrowing. We visualize the government's choice to reduce debt issuance in panel (b) of Figure 6, which shows that the schedule of spreads shifts up and becomes steeper and more convex. To understand the difference between the old loans and PEPP purchases, we note that removing the old loans makes all debt private at beginning of Covid. This reduces the country's fiscal space and implies a substantial increase in the spread, unless the government reduces its borrowing.

Row 6, labelled $\bar{q}b^{\text{new}} = 0.71(\bar{q}b + f)$, uses a different approach to assess the role of the old bailouts. In this counterfactual, we convert Greece's total liabilities at the beginning of 2020 from the observed split of 66 percent official and 34 percent private to the counterfactual split of 29 percent official and 71 percent private. We use a 29 percent share of official loans to match the average share of official loans to countries between 1995 and 2019, as reported by the World Bank's QPSD. In this case, the spread rises by 2.3 percentage points, which is close to the lower bound of our estimate of the missing spread. The logic is that as we tilt the composition of liabilities toward private debt, the gain of the government from defaulting rises, and investors demand a higher compensation to hold its bonds. Panel (c) of Figure 6 shows that the menu of spreads shifts up and becomes substantially steeper. As a result, the government chooses to borrow less during Covid, which reduces consumption and increases inequality.

Rows 7 and 8 of Table 5 consider the effects of changing the extent of debt relief under restructuring. Recall that in our baseline parameterization, the haircut rate is $\bar{\eta} = 0.47$. An interpretation of the bailout policies of the 2010s is that they allowed for only limited debt relief in order to protect foreign investors from losses, in exchange for longer-maturity official loans that reduced the welfare losses of default for Greece. To assess the role of debt relief within this coordinated set of policies, in row 7 we raise the haircut rate to $\bar{\eta} = 0.73$. A higher haircut increases the losses of lenders in the event of a restructuring and increases the incentive of the government to restructure, with both mechanisms causing foreign investors to demand higher compensation in order to break even. As we see in panel (d) of Figure 6, these mechanisms lead to a higher and steeper schedule of spreads. In equilibrium, the spread increases by 1.8 percentage points, and the government reduces significantly the amount of borrowing and transfers.[33] To the extent that old intervention policies limited haircuts upon default, we conclude that these policies played an important role for the stability of the spread during Covid. In row 8, we instead reduce the haircut rate to $\bar{\eta} = 0.22$. To the extent that Covid intervention policies signaled to governments and foreign investors more debt relief upon default, we conclude that these interventions do not explain the puzzle of missing spread.

To summarize, rows 5 to 8 of Table 5 demonstrate the importance of old bailout policies for the stability of the spread during Covid. The quantitative effects vary quite a bit, depending on whether one conceptualizes the old policies as removing all loans, or changing the composition of debt while keeping total debt constant, or limiting debt relief. However, in all cases these policies generate changes in the spread that are at least as large as the changes in the spread generated by the ECB purchases under PEPP during Covid. Further, the largest estimates of how old loan policies affect the spread during Covid coincide with the lower bound of our estimate of the missing spread.

5.3.4 Private Responses

In row 9 of Table 5, we consider the role of labor supply responses. In our baseline, the value of the Frisch elasticity was $\varepsilon = 0.56$, whereas now we make labor close to inelastic by setting

[33] Our estimate of the effect of haircut size on the spread is consistent with the empirical estimates of Cruces and Trebesch (2013), who estimate the effect of past restructuring events on future interest rate spreads. We interpret these estimates as the effects of different restructuring regimes in our setting, which are perceived to be permanent. The authors' estimates that are most consistent with our modeling of the restructuring process, imply that a 26 percentage points increase in $\bar{\eta}$ is associated with a 1.5 percentage points increase in the spread.

$\varepsilon = 0.1$. In this case, redistributive transfers become substantially less distortionary, which increases the willingness of the government to borrow and provide transfers. In anticipation of government's willingness to redistribute more during Covid, foreign investors increase the required compensation to hold debt. As seen from panel (e) of Figure 6, the schedule of spreads that the government faces shifts up and becomes steeper. The resulting equilibrium features a spread that is higher by 0.7 percentage point, lower borrowing and transfers, and higher inequality.

The recession in 2020 was unusual in that it featured a substantial increase in private savings, a feature of the data that our model replicates quite well. A priori, a plausible explanation for the low spread during Covid is that resources saved by a country's citizens are accessible to the government in order to repay external debts, so the relevant measure of indebtedness is net, and not gross, indebtedness. In order to assess the role of this mechanism, in row 10 of Table 5 we assume that optimizing households cannot save or dissave and are unexpectedly forced to choose private assets $a_{21} = a_{20}$. In panel (f) of Figure 6, we see that the schedule of spreads barely changes. While the equilibrium spread does not change, equilibrium allocations bear significant adjustments. Wealth effects on labor supply are the key mechanism accounting for this result. If the government maintains the same level of transfers under the baseline allocation and optimizing households are forced to consume these transfers, labor supply and output fall significantly. To avoid an even larger recession, the government cuts back on borrowing and transfers.[34]

Did spreads remain low because of a decline in the safe rate during Covid? To assess this possibility, in row 11 of Table 5, we increase the risk-free rate from 2 percent in the baseline to 3 percent. Recall that the government is relatively impatient, with a discount factor of 0.96. Reducing the distance between government's discount rate and the private sector's discount rate generates lower gains from intertemporal trade, and so the government engages in less borrowing. In panel (g) of Figure 6, we can see that the schedule of spreads shifts down relative to the baseline. We conclude that the decline in risk-free rate does not explain the puzzle of the missing spread, because in a counterfactual world with a higher risk-free rate, both the spread and borrowing are lower.

[34]In the baseline model with endogenous savings, a 10 percentage points increase in government debt is associated with a negligible drop in output. With constrained savings, a 10 percentage points increase in government debt is associated with a 5 percent drop in output.

5.3.5 Beliefs about the Persistence of Lockdowns

Row 12 of Table 5 presents our key counterfactual, which concerns the belief that lockdowns would not persist for a longer time. Recall that in our baseline parameterization, which matched the responses of the spread and debt during Covid, the expected duration of lockdowns is two years. We now raise the probability π_ℓ from 0.5 to 0.85, which matches the duration of Greek depression between 2009 and 2016.[35] As we can see in panel (h) of Figure 6, increasing the perceived persistence of lockdowns dramatically reduces the country's fiscal space by shifting the schedule of spreads upward. In the new equilibrium, the spread increases by 2.4 percentage points. In addition, borrowing decreases by 7 percentage points, transfers decrease by 10 percent, consumption drops by 9 percent, and inequality increases by 25 percentage points.

The mechanism by which a higher expected duration of lockdowns increases the spread is specific to the nature of the Covid shock. To illustrate this, in rows 13 and 14, we use either persistent or permanent productivity shocks to engineer a recession of similar magnitude to the one caused by lockdowns.[36] As the table shows, in this case the spread does not change significantly. Additionally, the government does not borrow as much, and transfers do not increase as much as they do under the lockdowns.

Why are lockdowns different from productivity shocks? The answer lies in the distributional nature of the lockdowns. In the absence of a policy intervention, lockdowns impact hand-to-mouth households most negatively. In our model, lockdowns result in a 43 percent drop in the pre-tax-and-transfer labor income of hand-to-mouth households, as opposed to a 2 percent increase in the income of optimizing households.[37] The heterogeneous impact of lockdowns increases substantially the government's incentive to borrow and transfer resources to hand-to-mouth households. Had lockdowns been perceived as more persistent, foreign investors would anticipate a higher redistributive motive from the government in the future. This expectation would have pushed the economy closer to default, with a higher spread and lower equilibrium

[35] Our counterfactual with $\pi_\ell = 0.85$ is reasonable in light of historical rare disasters. Barro and Ursua (2012) assemble a sample of 40 countries that extends back to 1870. The authors report a mean output decline of 21 percent during a disaster and a 4-year mean duration of disasters. Approximately 16 percent of observations have disasters that persist for 6 or more years.

[36] We reduce both traded and non-traded productivities by a common proportion that is set to match the fall in output from 2019 to 2020. For the case of persistent shocks, we introduce negative innovations to productivities and assume that productivities are expected to follow their autoregressive process in equation (20). For the case of permanent shocks, we lower the permanent components of productivities and adjust the innovations so that we replicate the same decline in output.

[37] Our estimate concerns the increase in inequality in the absence of policy responses. We do not compare this estimate with observed inequality measures, because measured inequality includes substantial policy responses that took place during Covid. For instance, paycheck protection programs increase the relative income of lower-income households relative to a counterfactual world without paycheck protection programs.

borrowing.

By contrast, productivity shocks do not affect the distribution of pre-tax-and-transfer labor income across households as much. With persistent productivity shocks, the drop in labor income is 10 percent for hand-to-mouth households and 7 percent for optimizing households. With permanent productivity shocks, the drop in labor income is 7 percent for hand-to-mouth households and 8 percent for optimizing households. Thus, the incentive of the government to redistribute resources during a recession caused by productivity shocks is muted, and the persistence of the shock does not matter quantitatively for borrowing, transfers, and the spread.

5.3.6 Interactions

Next, we consider interactions between various mechanisms. In row 15 of Table 5, we remove the ECB purchases under PEPP, as in row 1. At the same time we remove the old bailouts, as in row 5. The spread increases by 1.9 percentage points, which exceeds the sum of the individual effects by 0.7 percentage point. The interaction between the old and new loans is the closest analog to the estimates reported by Rostagno, Altavilla, Carboni, Lemke, Motto, and Saint-Guilhem (2021) on the cumulative effect of both APP and PEPP from 2014 to 2020. According to these authors, the combined effects of these policies is to depress the ten-year yields of Germany, France, Spain, and Italy by roughly 2 percentage points, which is close to our estimate of 1.9 percentage points.

In row 16, we interact the ECB purchases under PEPP with a higher expected duration of lockdowns, as in row 12. While the individual effects on the spread are 0.5 and 2.4 percentage points respectively, introducing both changes increases the spread by more than 5 percentage points. Considering the isolated effect of the PEPP, we conclude that ECB policies mostly ameliorated inequality during Covid. However, at the beginning of Covid, there was considerable uncertainty about the evolution of the virus, the invention of a vaccine, and the duration and economic impact of lockdowns. The counterfactual, in which we interact the PEPP policy with a higher expected duration of lockdowns, illustrates that these policies would have averted a significant sovereign debt crisis had lockdowns been perceived as more persistent by investors and governments.

5.3.7 Extended Lockdowns

Row 17 of Table 5 examines the case in which lockdowns extend to 2021. Compared with the baseline model, which does not feature lockdowns in 2021, this case generates a substantial drop in output and consumption. However, the spread increases by only one percentage point. This result suggests that the incidence of lockdowns is not as important as the expected duration of lockdowns for the stability of the spread. To illustrate this more formally, in row 18 we extend the lockdowns by one more year and increase π_ℓ to 0.85, as in the counterfactual in row 12. In this case, we find that the spread increases by 3.7 percentage points. The last row of the table illustrates that the spread would reach levels observed in the crisis of the 2010s if, in addition to the 2021 incidence and the higher expected duration of lockdowns, we remove the ECB purchases under PEPP. In this case, the probability of default exceeds 70 percent. Again, this result highlights that ECB policies would have averted a significant sovereign debt crisis had lockdowns been perceived as more persistent.

6 Conclusion

The goal of this paper is to understand the puzzling behavior of sovereign spreads during Covid. The puzzle is that advanced economies went through a major recession and expanded their fiscal policies by borrowing significantly, yet spreads on sovereign debt barely responded. Studying the most extreme manifestation of the puzzle, the experience of Greece, we proceeded in three steps. First, we developed a small open economy model with long-term debt and default, which we augmented it with official lenders, heterogeneous sectors and households, and constraints on consumption and labor supply to mimic the Covid lockdowns. Second, we showed that a quantitative version of the model is consistent with the observed boom-bust cycle of Greece before Covid and salient observations on the behavior of macro aggregates, government debt, and the sovereign spread during Covid. In our final step, we performed a series of counterfactual exercises to assess which forces account for the stability of the spread during Covid.

We reached several substantial conclusions. The government expanded fiscal policy by borrowing externally during Covid to ameliorate the uneven impact of lockdowns on the labor supply of poorer and asset-constrained households. Despite this expansion, the spread did not respond, because lockdowns were perceived as transitory and old bailouts allowed Greece to enter Covid with a debt composition that was less tilted toward defaultable private debt. By contrast, we find a smaller role for the new PEPP policies and for other margins such as lengthening maturity of debt, moral hazard, and private responses to government policies. While some of our lessons are specific to institutional details of the Greek sovereign debt markets in the 2010s, we conjecture that our analyses provide insights on the stability of the spread in other countries that also expanded their fiscal policy by borrowing externally, went through relatively shorted-lived recessions, and were subject to ECB interventions that purchased sovereign debt.

Methodologically, our paper contributes to the literature by improving upon the quantification of sovereign debt models and by extending these models to consider the distributional effects of shocks and the effects of lockdowns. On the policy side, we highlight the importance of the history of official lending for countries entering recessions and considering new debt issuances. We also conclude that ECB purchases of sovereign debt during Covid did not stabilize spreads so much, but allowed the government to provide increased transfers to households, which stabilized consumption and reduced inequality. A rationalization of the ECB policies during Covid is that they would have stabilized sovereign debt markets substantially had the lockdowns been perceived as more persistent by private investors.

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The Puzzling Behavior of Spreads during Covid

Online Appendix

Stelios Fourakis and Loukas Karabarbounis

Appendix A provides details for the measurement. Appendix B elaborates on some model elements. Appendix C presents our algorithm for solving the model and details of the simulations.

A Data

Risk premium and sovereign spread. In this section, we discuss why abstracting from the risk premium for the case of Greece is appropriate. Our starting point is the equilibrium price of an asset:

$$q_t = \mathbb{E}_t[M_{t,t+1}Q_{t+1}] = \mathbb{E}_t[M_{t,t+1}]\mathbb{E}_t[Q_{t+1}] + \mathrm{Cov}_t(M_{t,t+1}, Q_{t+1}), \tag{A.1}$$

where $M_{t,t+1}$ is the stochastic discount factor of the investor pricing the asset and Q_{t+1} is the payoff of the asset in period $t+1$. Our model assumes that (i) lenders are risk neutral and have a constant discount rate; and (ii) the price of the sovereign debt depends on fundamentals of the domestic economy, the amount of sovereign debt, and the country's status vis-a-vis private and official lenders. In other words, we have a model of q_t that assumes that $\mathbb{E}_t[M_{t,t+1}]$ is constant and the covariance term is 0,

$$q_t = \frac{1}{1+r}\mathbb{E}_t[Q_{t+1}]. \tag{A.2}$$

In the data there may be a nonzero risk premium for sovereign debt. To investigate this, our approach begins by predicting the model-consistent spread on the basis of the fundamentals of the domestic economy, the amount of sovereign debt, and the country's status vis-a-vis private and official lenders. Under the null hypothesis that our model generates the data, the residual between the observed spread and the predicted spread reflects the covariance term in equation (A.1).

We calculate the model-consistent bond price as

$$q_t = \frac{\lambda_p + \kappa_p}{\lambda_p + r + \mathrm{spread}_t}, \tag{A.3}$$

where spread_t is the observed spread, $r = 0.02$ is the risk-free rate, $\lambda_p = 0.10$ is the maturity rate, and $\kappa_p = 0.045$ is the coupon rate. We project this bond price from 2001 to 2019 on a

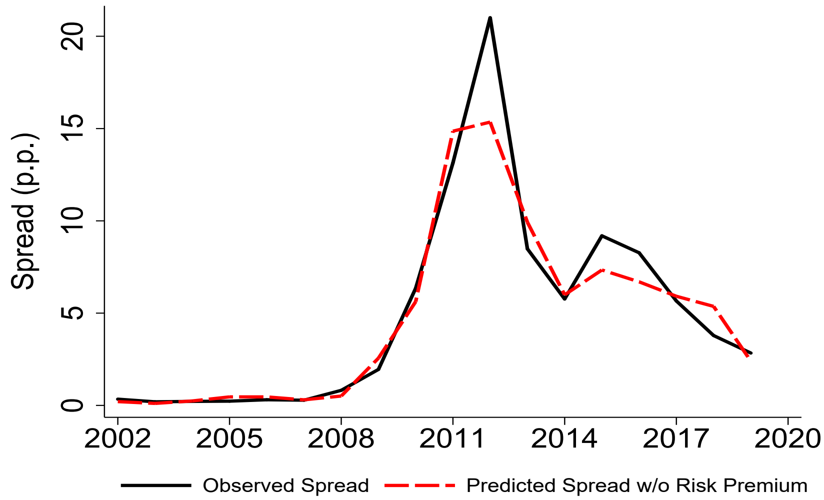

Figure A.1: Greek Observed and Predicted Sovereign Spread

dummy denoting whether the country has access to private debt markets, GDP growth, the debt-to-GDP ratio, and a full set of second degree terms involving these measures. We use monthly data to form the prediction.

In Figure A.1, we plot the observed spread and our prediction, both aggregated at the annual frequency as in the rest of our model. We interpret the difference between them as the effects of the omitted creditor-side variables that determine the risk premium.[1] It turns out that the small set of state variables that predict spreads under our model fits the data extremely well in sample, with the R-squared of the prediction being 93 percent. There are large residuals in 2012, which coincides with the peak of the eurozone debt crisis, and in 2015, which coincides with political instability and the referendum of exit from the euro. We find these deviations reassuring, because we would expect the risk premium to increase in precisely these two circumstances.

In sum, abstracting from the risk premium for the case of Greece is appropriate for two reasons. First, the predicted spread under our model that does not feature a risk premium tracks extremely closely the observed spread in the run up to the Greek crisis. We use the run-up to 2012 to estimate model parameters, which implies that the deviations in 2012 and 2015 are not relevant for the estimation of the parameters. Second, during Covid, one would need to argue that the risk premium fell dramatically in order to rationalize the puzzling behavior of the Greek spread. As discussed in the main text, the missing Greek spread during Covid

[1]Because the average residual is zero, the residuals represent only the relative size of the risk premium. In order to derive a meaningful representation of its absolute magnitude, we assume that the average risk premium until 2007 is zero and adjust the prediction accordingly.

is around 4 percentage points. In fact, if we use our prediction until 2019 to estimate out of sample the risk premium in 2020, we would obtain a decline in the risk premium of around 6 percentage points. We find such a decline in the risk premium during Covid implausible.

Adjusting the national accounts to confront to the model. Table A.1 shows which industries are classified as part of the traded sector and which are classified as part of the non-traded sector.

To understand the deviations of our model from the national income and product accounts, we write output in the model as

$$\begin{aligned} y &= p_T y_T + p_N y_N \\ &= p_T(c_T + g_T) + p_N(c_N + g_N) + \text{nx} \\ &= w(\ell_T + \ell_N). \end{aligned} \tag{A.4}$$

In the national accounts we have

$$\begin{aligned} Y &= P_T Y_T + P_N Y_N + \text{Taxes on Products} \\ &= P_T(C_T + X_T + G_T) + P_N(C_N + X_N + G_N) + \text{NX} \\ &= WL + RK, \end{aligned} \tag{A.5}$$

where we use uppercase letters for SNA concepts and lowercase letters for model concepts. On the production side, our model does not have taxes on products, and the value added by industry excludes other taxes on production. On the expenditure side, our model does not have investment. On the income side, our model does not have capital income generated by domestic capital.

Our adjustments begin by measuring the labor share of income for the aggregate economy,

$$s_\ell = \frac{\text{Compensation} \times \left(1 + \frac{\text{Total Hours} - \text{Hours Employees}}{\text{Hours Employees}}\right)}{\text{GDP} - \text{Taxes on Production}}. \tag{A.6}$$

The numerator of the labor share adds the labor income of the self-employed to the compensation of employees. The imputation of the labor income of the self-employed assumes that the self-employed have the same labor share as the rest of the economy (see Karabarbounis (2023) for more details).

The labor share of income in the non-traded sector is

$$s_{\ell N} = \frac{\text{Compensation}_N \times \left(1 + \frac{\text{Total Hours}_N - \text{Hours Employees}_N}{\text{Hours Employees}_N}\right)}{\text{Value Added}_N - \text{Other Taxes on Production}_N}, \tag{A.7}$$

and the labor share of income in the traded sector is

$$s_{\ell T} = \frac{\text{Compensation}_T \times \left(1 + \frac{\text{Total Hours}_T - \text{Hours Employees}_T}{\text{Hours Employees}_T}\right)}{\text{Value Added}_T - \text{Other Taxes on Production}_T}. \tag{A.8}$$

Table A.1: Traded and Non-Traded Sectors

Traded Sector	Non-Traded Sector
agriculture, forestry, and fishing	electricity, gas, steam
mining and quarrying	water supply, sewerage, waste
manufacturing	construction
land transport and pipelines transport	wholesale and retail trade
water transport	warehousing
air transport	postal and courier
	information and communication
	financial and insurance
	professional, scientific, and technical
	administrative and support services
	public administration and defence
	education
	human health and social work
	arts, entertainment, and recreation
	accommodation and food service
	other services

We note a difference between GDP and the sum of value added across sectors. GDP includes taxes on production less subsidies, which we allocate proportionally between labor and capital income. Value added at the industry level includes only other taxes on production, which are a subcomponent of taxes on production less subsidies. Thus, for the sectoral labor shares, we allocate other taxes on production less subsidies proportionally between labor and capital income.

We use the labor shares to map model concepts to their data counterparts. Output of non-traded goods in the model,

$$p_N y_N = s_{\ell N} \times \text{Value Added}_N + \frac{\text{Value Added}_N}{\text{Aggregate Value Added}} \times s_\ell \times \text{Taxes on Products}, \tag{A.9}$$

equals the labor income generated by the non-traded sectors plus a share of the missing taxes on production (called taxes on products) attributed to labor income. This share equals the share of value added of non-traded goods before the adjustment is made. Similarly, we measure output of traded goods in the model as

$$y_T = s_{\ell T} \times \text{Value Added}_T + \frac{\text{Value Added}_T}{\text{Aggregate Value Added}} \times s_\ell \times \text{Taxes on Products}. \tag{A.10}$$

Our next step is to construct measures of government and private consumption. We scale the corresponding measures in the data by the labor share of income, since our model does not have domestic capital. For government consumption of non-traded goods, we estimate

$$p_N g_N = (6/7)s_\ell \times \text{Government Consumption}, \tag{A.11}$$

where the factor 6/7 comes from the estimates of Chodorow-Reich, Karabarbounis, and Kekre (2023) for the fraction of government consumption that is accruing to non-traded goods. We thus obtain government consumption of traded goods:

$$g_T = (1/7)s_\ell \times \text{Government Consumption}. \tag{A.12}$$

To measure non-traded goods, we use the market clearing condition,

$$c_N = y_N - g_N. \tag{A.13}$$

To adjust for the lack of investment from our model, we equate the sum of private consumption by sector to the sum of private consumption and gross capital formation in the SNA, scaled down by the labor income share. Given the measured consumption of non-traded goods, we then obtain consumption of traded goods residually:

$$p_T c_T = s_\ell \times (\text{Hh Consumption} + \text{Gross Capital Formation}) - p_N c_N. \tag{A.14}$$

These adjustments imply that net exports in the model equal net exports in the data, again scaled by the labor income share:

$$\text{nx} = y_T - c_T - g_T = s_\ell \times \text{NX}. \tag{A.15}$$

Allocating issuances between revenues from issuing private debt and flows of official loans. Given issuances in equation (19) of the main text, default dates, and maturities, we allocate to private debt

$$q_t(b_{t+1} - (1-\lambda_p)b_t) = \begin{cases} \text{issuance}_t & \text{if } t < 2018 \text{ and } d_{t+1} = 0, \\ 0 & \text{if } t = 2018, \\ \text{issuance}_t & \text{if } t = 2019, \\ \text{issuance}_t - \text{PEPP}_t & \text{if } t \geq 2020, \end{cases} \tag{A.16}$$

and we allocate to official loans

$$\hat{\delta}_t = f_{t+1} - (1-\lambda_g) f_t = \begin{cases} \text{issuance}_t & \text{if } t < 2018 \text{ and } d_{t+1} = 1, \\ \text{issuance}_t & \text{if } t = 2018, \\ 0 & \text{if } t = 2019, \\ \text{PEPP}_t & \text{if } t \geq 2020. \end{cases} \tag{A.17}$$

The variable PEPP equals the ECB's estimate of purchases of Greek sovereign debt in secondary markets during the Covid period.

In Figure A.2, we compare the adjusted data through the lens our model with the raw data from statistical agencies reported in national accounts and the ECB.

B Model

Equivalence of loans and purchases. In addition to providing loans $\hat{\delta}_t$, official lenders can purchase privately-held government debt from investors in secondary markets. We demonstrate that loans from official lenders and purchases of sovereign debt in secondary markets are equivalent for allocations when accrued profits Π^g from the purchases of the sovereign debt are rebated to the country.

Let v_t denote the stock of these purchased debts at the beginning of period t and let $\bar{q}_t$ denote the average price at which it was purchased. The interest rate realized on investments in these debts is

$$\frac{(\lambda_p + \kappa_p + (1-\lambda_p)\bar{q}_t)v_t}{\bar{q}_t v_t} = \frac{\lambda_p + \kappa_p}{\bar{q}_t} - \lambda_p = \bar{r}_t. \tag{A.18}$$

Since the official lender's cost of capital is the risk-free rate r, total profits on its investments are

$$\Pi_t^g = (\bar{r}_t - r)\bar{q}_t v_t = \left(\frac{\lambda_p + \kappa_p}{\bar{q}_t} - \lambda_p - r \right) \bar{q}_t v_t = (\lambda_p + \kappa_p) v_t - (\lambda_p + r)\bar{q}_t v_t. \tag{A.19}$$

We assume that before the government chooses how much debt it intends to issue, the official lender announces how much debt it intends to buy this period, or, equivalently, how much debt it intends to hold, if possible, at the end of the period $\hat{v}_{t+1}$. Let $\hat{b}_{t+1}$ denote the amount of privately-held debt right after the auction of any new issuances or buyback of any existing debt. Privately-held bonds at the end of the period are

$$b_{t+1} = \max\{0, \hat{b}_{t+1} - (\hat{v}_{t+1} - (1-\lambda_p)v_t)\}. \tag{A.20}$$

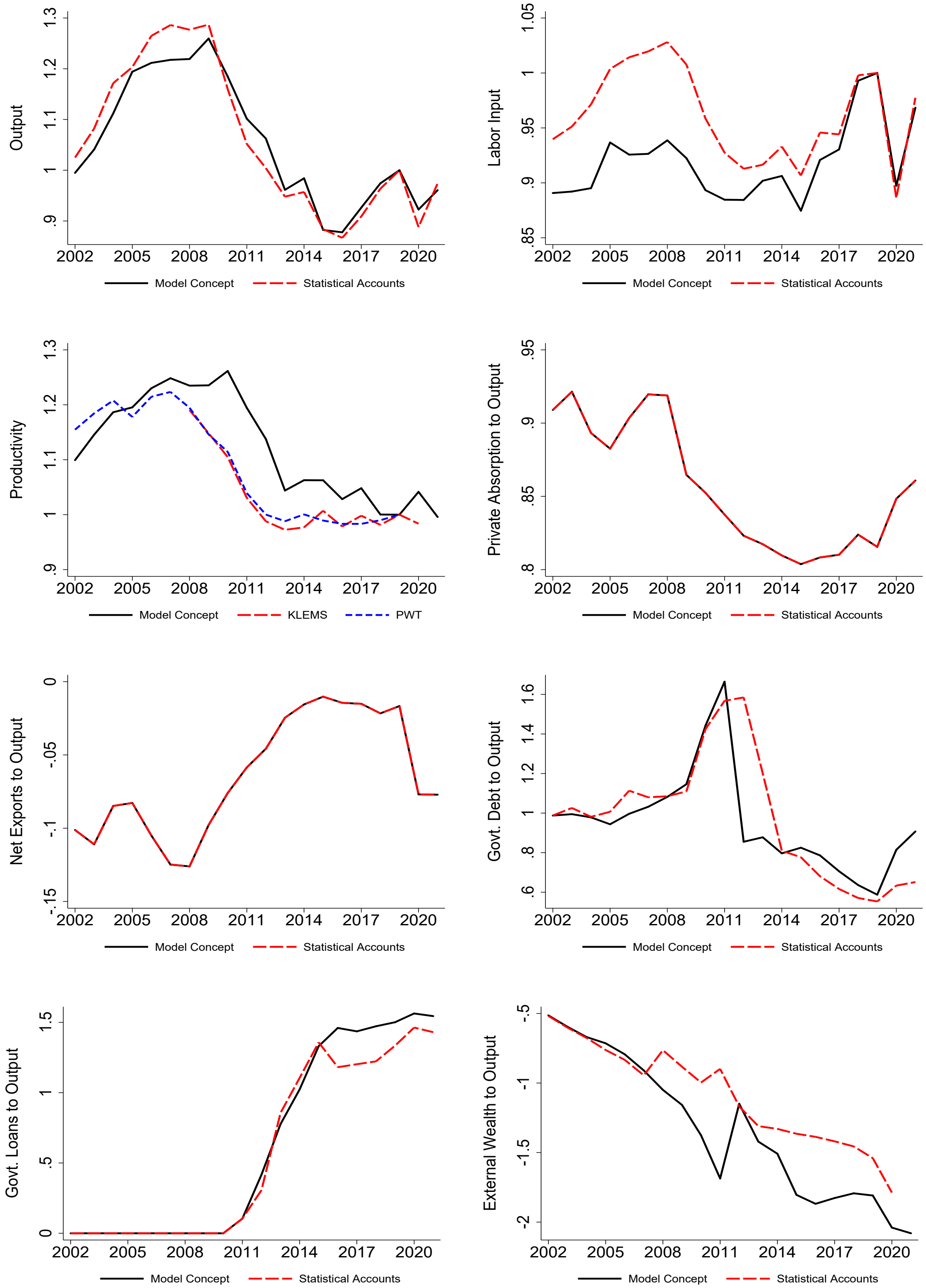

Figure A.2: Model versus Statistical Concepts

Officially-held bonds are

$$v_{t+1} = (1-\lambda_p)v_t + \min\{\hat{v}_{t+1} - (1-\lambda_p)v_t, \hat{b}_{t+1}\}. \tag{A.21}$$

The average price at which debt holdings were purchased is

$$\bar{q}_{t+1} = \frac{(1-\lambda_p)\bar{q}_t v_t + (v_{t+1} - (1-\lambda_p)v_t)q_t}{v_{t+1}}, \tag{A.22}$$

which implies that the book value of the official lender's debt holdings evolves as

$$\bar{q}_{t+1}v_{t+1} = (1-\lambda_p)\bar{q}_t v_t + (v_{t+1} - (1-\lambda_p)v_t)q_t. \tag{A.23}$$

The government budget constraint is

$$g_{Tt} + p_{Nt}g_{Nt} + T_t + (\lambda_p+\kappa_p)(b_t+v_t) + (\lambda_g+\kappa_g)f_t = \tau_t y_t + q_t(\hat{b}_{t+1} - (1-\lambda_p)b_t) - i_t + \hat{\delta}_t + \Pi_t^g, \tag{A.24}$$

where profits Π_t^g are rebated to the government. Substituting these profits from equation (A.19) yields

$$\begin{aligned} g_{Tt} + p_{Nt}g_{Nt} + T_t + (\lambda_p+\kappa_p)(b_t+v_t) + (\lambda_g+\kappa_g)f_t = {} & \tau_t y_t + q_t(\hat{b}_{t+1} - (1-\lambda_p)b_t) - i_t \\ & + \hat{\delta}_t + (\lambda_p+\kappa_p)v_t - (\lambda_p + r)\bar{q}_t v_t. \end{aligned} \tag{A.25}$$

Next, we use that the risk-free price of official loans is equal to one ($\kappa_g = r$) and separate $\hat{b}_{t+1}$ into the portion that will be privately held at the end of the period, b_{t+1}, and the portion that the official lender will purchase after the auction, $v_{t+1} - (1-\lambda_p)v_t$. Thus, we write the government budget constraint as

$$\begin{aligned} g_{Tt} + p_{Nt}g_{Nt} + T_t + (\lambda_p+\kappa_p)b_t + (\lambda_g+\kappa_g)(f_t + \bar{q}_t v_t) = {} & \tau_t y_t + q_t(b_{t+1} - (1-\lambda_p)b_t) - i_t \\ & + \hat{\delta}_t + q_t(v_{t+1} - (1-\lambda_p)v_t) \\ & + (\lambda_g - \lambda_p)\bar{q}_t v_t. \end{aligned} \tag{A.26}$$

To see the equivalence between loans and repurchases, let us consider first the case of $\lambda_g = \lambda_p$, in which the last term of equation (A.26) becomes zero. In this case, both the stocks f_t and $\bar{q}_t v_t$ and their increments $\hat{\delta}_t$ and $q_t(v_{t+1} - (1-\lambda_p)v_t)$ are perfect substitutes. In the more general case with $\lambda_g \neq \lambda_p$, the flow of official loans $\hat{\delta}_t$ can be adjusted appropriately to maintain the equivalence.

External positions. Let m_t be government's borrowing position and ι_t be the effective interest rate on government's liabilities. We define

$$\begin{aligned} m_{t+1} - (1+\iota_t)m_t \equiv {} & q_t(b_{t+1} - (1-\lambda_p)b_t) + \hat{\delta}_t - \mathbb{I}(d_t = \eta_{t+1} = 0)(\lambda_p+\kappa_p)b_t \\ & - (1 - \mathbb{I}(d_t = \eta_{t+1} = 0))(\lambda_d + \kappa_d)b_t - (\lambda_g+\kappa_g)f_t. \end{aligned} \tag{A.27}$$

Using this definition on the budget constraints of households and the government and the market clearing condition for non-traded goods leads to

$$c_{Tt} + g_{Tt} = y_{Tt} + [(1+r)a_t - a_{t+1}] - [(1+\iota_t)m_t - m_{t+1}], \tag{A.28}$$

where $c_{Tt} = \gamma c^o_{Tt} + (1-\gamma)c^h_{Tt}$ is aggregate consumption of traded goods and $a_t = \gamma a^o_t$ is aggregate private savings. Net exports are $\mathrm{nx}_t = y_{Tt} - c_{Tt} - g_{Tt} = y_t - c_t - g_{Tt} - p_{Nt}g_{Nt}$ and the external wealth of the country is $\mathrm{ew}_t = a_t - m_t$. Thus, the current account is

$$\mathrm{ca}_t = \mathrm{ew}_{t+1} - \mathrm{ew}_t = \mathrm{nx}_t + (ra_t - \iota_t m_t), \tag{A.29}$$

where $ra_t - \iota_t m_t$ equals net income and transfers from abroad.

Issuance cost. In our model, we have long-term debt and non-zero recovery. Thus, we use an issuance cost $i(.)$ to reduce the government's incentive to dilute to an extreme degree the debt before defaulting. See Chatterjee and Eyigungor (2015) for details on the economics of such behavior. The cost is continuous and, for each (b_t, b_{t+1}), depends on the one period ahead default probability $\mathbb{E}_t[\mathbb{I}\{\eta_{t+2}(s_{t+1} > 0\}]$:

$$i_t = i\Big(\mathbb{E}_t[\mathbb{I}\{\eta_{t+2}(s_{t+1} > 0\}]\Big) q_t(b_{t+1} - (1-\lambda_p)b_t),$$

where

$$i(x) = \begin{cases} \frac{1}{2}\left(1 + sin\left(\left(\frac{x-\bar{d}}{1-\bar{d}} - \frac{1}{2}\right)\pi\right)\right), & b_{t+1} - (1-\lambda_p)b_t > 0, \\ 0, & b_{t+1} - (1-\lambda_p)b_t \leq 0. \end{cases}$$

Along the equilibrium path, the issuance cost is almost always zero.

Taste shocks. In order to robustly compute the solution to our model, we augment the model with a set of taste shocks over the decisions available to the government at any point in time, following Dvorkin, Sanchez, Sapriza, and Yurdagul (2021).[2] Specifically, we assume that there are Generalized Type I Extreme Value preference shocks associated with the set of choice profiles available to the government at the beginning of each period. When the government enters the period in bad credit standing, these choice profiles are $\{(\eta_{t+1} = 0), (\eta_{t+1} = \bar{\eta})\}$.

[2] The sovereign default literature has concluded that, even in simpler models than ours with long-term debt, it is impossible to compute robustly pure strategy equilibria in a discrete state space representation. Motivated by the fact that mixed strategy solutions are even harder to compute, Chatterjee and Eyigungor (2012) prove the existence of a pure strategy equilibrium and provide an algorithm to find equilibria by adding an i.i.d. continuous random variable that affects choices in each period. Introducing this variable makes the probability of choosing each feasible level of debt in the next period continuous in the price function and the continuation value function.

Table A.2: Moments Targeted

Statistic ($\times$100)	Data	Model
$\log y_{09} - \log y_{02}$	26.5	24.7
$\log y_{05} - \log y_{04}$	8.2	-0.2
$\log y_{15} - \log y_{09}$	-37.7	-31.5
$\log b_{10} - \log b_{03}$	79.8	91.0
$\log a_{10} - \log a_{03}$	-32.5	-40.4
$\log a_{15} - \log a_{10}$	22.0	13.3
$\log T_{09} - \log T_{02}$	14.9	3.5
spread_{10}	6.3	7.4
spread_{11}	13.1	13.9

When the government is in good credit standing, these choice profiles are $\{\{(\eta_{t+1} = 0, b_{t+1} = b')\}_{b' \in \mathscr{B}}, (\eta_{t+1} = \bar{\eta})\}$, where the set of points in the grid of b_{t+1} is $\mathscr{B}$.

Calibration of parameters. We follow a two step process to calibrate the parameters shown in Table 3. In the first step, we take as given that the model matches the path of the dynamic model variables, a and b, and pick $\theta^o, \theta^h, \sigma, \epsilon, \xi$ so that the model produces time series of $y, c, T, \frac{\gamma w \theta^o \ell^o}{(1-\gamma) w \theta^h \ell^h}, \frac{\gamma[(1-\tau) w \theta^o \ell^o + ra + T^o]}{(1-\gamma)[(1-\tau) w \theta^o \ell^o + ra + T^h]}$ that match their data analogs. The ratio $\frac{\gamma w \theta^o \ell^o}{(1-\gamma) w \theta^h \ell^h}$ is the pre-tax-and-transfer inequality and the ratio $\frac{\gamma[(1-\tau) w \theta^o \ell^o + ra + T^o]}{(1-\gamma)[(1-\tau) w \theta^o \ell^o + ra + T^h]}$ is the post-tax-and-transfer inequality, which we obtain from the Luxembourg Income Study (`https://shorturl.at/QY146`). We also pick χ^o, χ^h to normalize labor supplies in 2019 to one. In the second step, we calibrate the remaining 8 parameters, $\beta_c, \beta_g, \zeta, \alpha, , \mu, \mu_N, \mu_T, \pi_{\hat{\delta}}$, so that the dynamic model reproduces as closely as possible the targets shown in Table A.2.

Long-run moments. In Table A.3, we compare the long-run moments generated by the model with the sample averages in the data. We perform the comparison under two regimes. The first regime is between 2002 and 2010, before the sovereign debt crisis. The second regime covers the sovereign debt crisis after 2011.

C Computation

Solution. Our strategy begins by solving for the optimal policy of households, conditional on the government's policy. Then, we solve for the optimal choices of the government, given the optimal responses of households to these policies. We use a discrete state space approximation

Table A.3: Long-Run Moments

	2002-2010 Regime		2011-2019 Regime	
Statistic	Data	Model	Data	Model
$\mathbb{E}[b_{t+1}/y_t]$	1.15	1.72	0.75	0.55
$\mathbb{E}[a_{t+1}/y_t]$	0.16	0.00	0.29	0.00
$\mathbb{E}[f_{t+1}/y_t]$	0.01	0.06	1.21	0.38
$\mathbb{E}[\mathbb{I}\{\eta_{t+1} > 0\}]$	0.11	0.00	0.00	0.00
$100 \times \mathbb{E}[\text{spread}_t]$	1.19	0.16	8.68	2.84
$100 \times \sigma[\text{spread}_t]$	2.02	0.11	5.57	3.84
$\mathbb{E}[T_t/y_t]$	0.26	0.14	0.32	0.29
$\mathbb{E}[(g_{Tt} + p_{Nt}g_{Nt})/y_t]$	0.20	0.22	0.21	0.21
$\rho[\text{spread}_t, \log(y_t)]$	0.22	-0.07	0.41	-0.30
$\rho[\text{spread}_t, b_{t+1}/y_t]$	0.83	0.56	0.52	0.88
$\rho[\log(c_t), \log(y_t)]$	0.83	0.60	0.89	0.74
$\rho[\log(g_{Tt} + p_{Nt}g_{Nt}), \log(y_t)]$	0.83	0.91	0.85	0.96
$\rho[\log(c_t), T_t]$	0.69	0.52	0.58	0.24
$\rho[\log(g_{Tt} + p_{Nt}g_{Nt}), T_t]$	0.87	-0.02	0.63	-0.25
$\rho[\log(g_{Tt} + p_{Nt}g_{Nt}), \log(c_t)]$	0.71	0.82	0.85	0.87

of the stochastic processes.[3] For the endogenous state variables b, a, and f, we use fixed, evenly spaced grids for the beginning-of-period values. We allow end-of-period values a' and f' to be off grid and interpolate the associated values using cubic splines. We restrict b', a', and f' to lie within the bounds of their grids. Whenever the flow of loans implied by $\hat{\delta}$ would result in f' being above the maximum value in the grid, that flow is reduced so that the f' implied by the law of motion for f is exactly equal to the maximum value in the grid for f.[4]

To describe our computational procedure, it is useful to collect state variables in the vector $\hat{s} = (z_N, z_T, g_N, g_T, \tau, d, \delta, \text{lock})$. The set of objects used to determine convergence consists of the continuation value of the government, the price of the debt, the probability of restructuring in the next period, and the expected marginal utility of traded consumption of optimizing

[3]We use 13 points for z_N and 11 points for z_T conditional on z_N. We use 1 point for g_N and g_T conditional on both z_N and z_T, so government consumptions are set at their conditional means.

[4]For our approximation, we use 41 points for b, 18 points for a, and 11 points for f. We use 151 points for b', which is chosen directly from the grid.

households in the next period,

$$\Big\{\mathbb{E}[V(\hat{s}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1}, \nu_{t+1})|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t],$$
$$q(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1}),$$
$$\Pr(\eta_{t+2}(\hat{s}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1}, \nu_{t+1}) > 0|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t),$$
$$\mathbb{E}\left[\beta_c(1+r)U_T(\hat{s}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1})|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t\right]\Big\}.$$

Here, ν_{t+1} is a vector of preference shocks associated with the choices available to the government, which we described in Appendix B.

Our solution algorithm proceeds in the following steps.

1. *Computation before iteration.* Before beginning the policy function and value function iterations, we compute a number of key equilibrium outcomes conditional on $\hat{s}_t$ and certain endogenous variables. This step allows us to compute the full model in a tractable way because it needs to be performed only once.

   (a) Taking as given $\hat{s}_t$, we calculate the expected marginal utility of traded consumption optimizing households in the next period ($\bar{E}_{t+1}$) and the government's net revenue from borrowing and debt service (NB_t). When the government is in good credit standing, NB_t is

   $$q_t(b_{t+1} - (1-\lambda_p)b_t) + \hat{\delta}_t - i_t - (\lambda_p + \kappa_p)b_t - (\lambda_g + \kappa_g)f_t.$$

   When it is in bad standing, NB_t is

   $$\hat{\delta}_t - (\lambda_d(\eta_{t+1}, \hat{\delta}_t) + \kappa_d(\eta_{t+1}, \hat{\delta}_t))b_t - (\lambda_g + \kappa_g)f_t.$$

   The values of $\hat{s}_t$, $\bar{E}_{t+1}$, and NB_t uniquely determine the equilibrium outcomes in the domestic economy,

   $$\{w_t, p_{Nt}, P_t\}, \{c_t^o, c_{Tt}^o, c_{Nt}^o, \ell_t^o\}, \{c_t^h, c_{Tt}^h, c_{Nt}^h, \ell_t^h\}, \{T_t, T_t^h, T_t^o\}, \{y_{Nt}, y_{Tt}, \ell_{Nt}, \ell_{Tt}\}$$

   as well as the net savings of the optimizing households:

   $$NS_t = a_{t+1} - (1+r)a_t.$$

   The equilibrium is determined from the following system of 19 equations that can be solved for 19 unknowns. Beginning with the case of lock $= 0$, and dropping time subscripts to ease the notation, the system is:

$$
\begin{aligned}
w &= z_T & w &= p_N z_N \\
\left(\frac{g}{\bar{g}}\right)^{\alpha} u'(c^o)\frac{1}{P} &= \bar{E} & P &= \left(\omega_c + (1-\omega_c)p_N^{1-\phi}\right)^{\frac{1}{1-\phi}} \\
Pc^o + NS &= (1-\tau)w\theta^o \ell_o + T_o & c^o &= c(c_T^o, c_N^o) \\
Pc^h &= (1-\tau)w\theta^h \ell^h + T^h & c^h &= c(c_T^h, c_N^h) \\
u'(c^o)\frac{(1-\tau)w\theta^o}{P} &= v'(\ell_o) & \frac{c_T^o}{c_N^o} &= \frac{\omega_c}{1-\omega_c}p_N^{\phi} \\
u'(c^h)\frac{(1-\tau)w\theta^h}{P} &= v'(\ell^h) & \frac{c_T^h}{c_N^h} &= \frac{\omega_c}{1-\omega_c}p_N^{\phi} \\
p_N g_N + g_T + T &= \tau w(\ell_T + \ell_N) + NB & T^o &= \xi T^h \\
T &= (1-\gamma)T^h + \gamma T^o & y_T &= z_T \ell_T \\
y_N &= z_N \ell_N & y_N &= g_N + \gamma c_N^o + (1-\gamma)c_N^h \\
\ell_T + \ell_N &= \gamma\theta^o \ell_o + (1-\gamma)\theta^h \ell^h.
\end{aligned}
$$

When lock = 1, there are additional inequality constraints, and some of the above equations may not hold. In particular, households may not be able to choose ratios of traded to non-traded consumption as in the unconstrained CES demand system above and labor supply in an interior solution. When this is the case, we use $p_N c_N^i + c_T^i$ instead of Pc^i in the budget constraints of the households and the binding constraints replace optimality conditions in the system above.

(b) We also compute a second set of equilibrium values in which the value of NS_t is taken as given, but the value of $\bar{E}_t$ is solved for. This second set of values allows us to compute period payoffs for the government directly from $(\hat{s}_t, NS_t, NB_t)$, regardless of whether the Euler equation holds or not. We write the equilibrium payoff to the government from these outcomes as $\hat{U}(\hat{s}, NS, NB)$ and the equilibrium marginal utility of tradable consumption for optimizing households as $\hat{E}(\hat{s}, NS, NB)$.

Since these computations only need to be performed once, we use very fine grids for $\bar{E}$, NS, and NB in order to increase the accuracy of the approximations.

2. *Value/Policy Function Iteration.* Each time we begin an iteration, we have in memory a

guess for the set of objects used to determine convergence

$$\Big\{\mathbb{E}[V(\hat{s}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1}, \nu_{t+1})|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t],$$
$$q(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1}),$$
$$\Pr(\eta_{t+2}(\hat{s}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1}, \nu_{t+1}) > 0|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t),$$
$$\mathbb{E}\left[\beta_c(1+r)U_T(\hat{s}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1})|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t\right]\Big\}.$$

Given this guess, we proceed as follows.

(a) First, we solve for the policy functions of the households, conditional on the government's policy, using the endogenous grid method for policy function iteration, as described by Carroll (2006). Specifically, for each $\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, b_t, b_{t+1}, a_{t+1}$, we use our computed solutions to determine the implied NS_t, which immediately yields the a_t such that a_{t+1} is optimal. In order to do this, we calculate f_{t+1} using the law of motion for f, calculate NB_t using its definition and our guess for the price function, and take $\bar{E}_t$ directly from our guess. This procedure yields the inverse policy function $a^\star(a')$ for every $\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, b_t, b_{t+1}$. We then use linear interpolation to obtain the values of $a'^\star$ associated with points $a_t \in \mathscr{A}$, i.e. $a'^\star(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, b_{t+1})$.

(b) Given the optimizing households' conditional policy functions, we then step back to the government's decision problems, given $\hat{s}_t, \eta_{t+1}, \hat{\delta}_t$. When the government is in bad credit standing, then it has no decisions to make, and its payoff is given by:

$$\begin{aligned}
V^d(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t) &= \hat{U}(\hat{s}_t, NS_t, NB_t) \\
&\quad + \beta_g \mathbb{E}[V(\hat{s}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1}, \nu_{t+1})|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t], \\
f_{t+1} &= (1-\lambda_g)f_t + \hat{\delta}_t, \\
b_{t+1} &= (1-\eta_{t+1})(1-\lambda_d(\eta_{t+1}, \hat{\delta}_t))b_t, \\
a_{t+1} &= a'^\star(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, b_{t+1}), \\
NS_t &= a_{t+1} - (1+r)a_t, \\
NB_t &= \hat{\delta}_t - (\lambda_d(\eta_{t+1}, \hat{\delta}_t) + \kappa_d(\eta_{t+1}, \hat{\delta}_t))b_t - (\lambda_g + \kappa_g)f_t.
\end{aligned}$$

We can also calculate the payoff to lenders as

$$
\begin{aligned}
Q^d(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t) = {} & (\lambda_d(\eta_{t+1}, \hat{\delta}_t) + \kappa_d(\eta_{t+1}, \hat{\delta}_t)) \\
& + (1-\eta_{t+1})(1-\lambda_d(\eta_{t+1}, \hat{\delta}_t)) q(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1}), \\
f_{t+1} = {} & (1-\lambda_g) f_t + \hat{\delta}_t, \\
b_{t+1} = {} & (1-\eta_{t+1})(1-\lambda_d(\eta_{t+1}, \hat{\delta}_t)) b_t, \\
a_{t+1} = {} & a'^{\star}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, b_{t+1}),
\end{aligned}
$$

and the marginal utility of traded consumption of optimizing households as

$$
\begin{aligned}
U_T^d(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t) = {} & \hat{E}(\hat{s}_t, NS_t, NB_t), \\
f_{t+1} = {} & (1-\lambda_g) f_t + \hat{\delta}_t, \\
b_{t+1} = {} & (1-\eta_{t+1})(1-\lambda_d(\eta_{t+1}, \hat{\delta}_t)) b_t, \\
a_{t+1} = {} & a'^{\star}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, b_{t+1}), \\
NS_t = {} & a_{t+1} - (1+r) a_t, \\
NB_t = {} & \hat{\delta}_t - (\lambda_d(\eta_{t+1}, \hat{\delta}_t) + \kappa_d(\eta_{t+1}, \hat{\delta}_t)) b_t - (\lambda_g + \kappa_g) f_t.
\end{aligned}
$$

When the government is in good credit standing, then it chooses how much to borrow b_{t+1}, and its payoff is given by:

$$
\begin{aligned}
V^n(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, \nu_t) = {} & \max_{b_{t+1} \in \mathscr{B}} \hat{U}(\hat{s}_t, NS_t, NB_t) + \nu_t(\eta_{t+1}, b_{t+1}) \\
& + \beta_g \mathbb{E}[V(\hat{s}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1}, \nu_{t+1}) | \hat{s}_t, \eta_{t+1}, \hat{\delta}_t], \\
f_{t+1} = {} & (1-\lambda_g) f_t + \hat{\delta}_t, \\
a_{t+1} = {} & a'^{\star}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, b_{t+1}), \\
NS_t = {} & a_{t+1} - (1+r) a_t, \\
NB_t = {} & q(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1})(b_{t+1} - (1-\lambda_p) b_t) + \hat{\delta}_t \\
& - (\lambda_p + \kappa_p) b_t - (\lambda_g + \kappa_g) f_t - i_t.
\end{aligned}
$$

With our assumptions about the distribution of the preference shocks, the set of values of feasible choices b_{t+1} determine their choice probabilities. We write these conditional choice probabilities as $\Pr^{nc}(b_{t+1} | \hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t)$ and the value of the government's objective function, excluding the contribution of the preference shocks, for a given choice of b_{t+1} as $V^{nc}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, b_{t+1})$.

The possible payoffs to lenders are:

$$
\begin{aligned}
Q^{nc}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, b_{t+1}) &= \lambda_p + \kappa_p + (1-\lambda_p) q(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1}), \\
f_{t+1} &= (1-\lambda_g) f_t + \hat{\delta}_t, \\
a_{t+1} &= a'^{\star}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, b_{t+1}),
\end{aligned}
$$

and the marginal utility of traded consumption of optimizing households is:

$$
\begin{aligned}
U_T^{nc}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, b_{t+1}) &= \hat{E}(\hat{s}_t, NS_t, NB_t), \\
f_{t+1} &= (1-\lambda_g) f_t + \hat{\delta}_t, \\
a_{t+1} &= a'^{\star}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, b_{t+1}), \\
NS_t &= a_{t+1} - (1+r) a_t, \\
NB_t &= q(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1})(b_{t+1} - (1-\lambda_p) b_t) + \hat{\delta}_t \\
&\quad - (\lambda_p + \kappa_p) b_t - (\lambda_g + \kappa_g) f_t - i_t.
\end{aligned}
$$

The expected payoff to lenders conditional on repayment is:

$$
Q^n(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t) = \sum_{b_{t+1} \in \mathscr{B}} \Pr^{nc}(b_{t+1} | \hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t) Q^{nc}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, b_{t+1}),
$$

and the expected marginal utility of traded consumption of optimizing households:

$$
U_T^n(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t) = \sum_{b_{t+1} \in \mathscr{B}} \Pr^{nc}(b_{t+1} | \hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t) U_T^{nc}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t, b_{t+1}).
$$

(c) Next, we step back to the point in time when the government chooses η_{t+1}, before $\hat{\delta}_t$ is realized. We calculate the expected value to the government of choosing $\eta_{t+1} = \bar{\eta}$ as

$$
\bar{V}^d(\hat{s}_t, \bar{\eta}, f_t, a_t, b_t, \nu_t) = \int V^d(\hat{s}_t, \bar{\eta}, \hat{\delta}_t, f_t, a_t, b_t) \mathrm{d}F(\hat{\delta}_t | \bar{\eta}, \delta_t) + \nu_t(\bar{\eta}).
$$

Since $\hat{\delta}_t = \delta_t$ with probability 1 whenever $\eta_{t+1} = 0$, the expected value to the government of choosing $\eta_{t+1} = 0$ is simply

$$
\bar{V}^n(\hat{s}_t, 0, f_t, a_t, b_t, \nu_t) = \max_{b_{t+1} \in \mathscr{B}} \{V^{nc}(\hat{s}_t, 0, \delta_t, f_t, a_t, b_t, b_{t+1}) + \nu_t(0, b_{t+1})\},
$$

if the government enters the period in good standing, and

$$
\bar{V}^d(\hat{s}_t, 0, f_t, a_t, b_t, \nu_t) = V^d(\hat{s}_t, 0, \delta_t, f_t, a_t, b_t) + \nu_t(0, (1-\lambda_d(0, \delta_t)) b_t),
$$

if the government enters the period in bad standing. When the government enters the period in good standing, we use the set of values $\{\{V^{nc}(\hat{s}_t, 0, \delta_t, f_t, a_t, b_t, b_{t+1}) + \nu_t(0, b_{t+1})\}_{b_{t+1}\in\mathscr{B}}, \bar{V}^d(\hat{s}_t, f_t, a_t, b_t, \nu_t)\}$ to calculate the probability that it chooses to restructure. When the government enters the period in bad standing, we instead use the set of values $\{\bar{V}^d(\hat{s}_t, \bar{\eta}, f_t, a_t, b_t, \nu_t), \bar{V}^d(\hat{s}_t, 0, f_t, a_t, b_t, \nu_t)\}$ to calculate the probability that it chooses to restructure. Call these probabilities $\Pr(\eta_{t+1} = \bar{\eta}|\hat{s}_t, \delta_t, f_t, a_t, b_t)$. The two sets of values above also allow us to calculate the ex ante expected value to the government, that is, before the preference shocks are realized, of entering the period in state $(\hat{s}_t, f_t, a_t, b_t)$, which is $\mathbb{E}_{\nu_t}[V(\hat{s}_t, f_t, a_t, b_t, \nu_t)]$.

Furthermore, we can calculate the ex ante payoff to private bondholders as

$$\begin{aligned} Q(\hat{s}_t, f_t, a_t, b_t) = \Pr(\eta_{t+1} = \bar{\eta}|\hat{s}_t, \delta_t, f_t, a_t, b_t) &\int Q^d(\hat{s}_t, \bar{\eta}, \hat{\delta}_t, f_t, a_t, b_t)\mathrm{d}F(\hat{\delta}_t|\bar{\eta}, \delta_t) \\ +\Pr(\eta_{t+1} = 0|\hat{s}_t, \delta_t, f_t, a_t, b_t)&\Big((1 - d_t)Q^n(\hat{s}_t, 0, \hat{\delta}_t, f_t, a_t, b_t) \\ &+ d_t Q^d(\hat{s}_t, 0, \hat{\delta}_t, f_t, a_t, b_t)\Big), \end{aligned}$$

and the ex ante expected marginal utility of traded consumption of optimizing households as

$$\begin{aligned} U_T(\hat{s}_t, f_t, a_t, b_t) = \Pr(\eta_{t+1} = \bar{\eta}|\hat{s}_t, \delta_t, f_t, a_t, b_t) &\int U_T^d(\hat{s}_t, \bar{\eta}, \hat{\delta}_t, f_t, a_t, b_t)\mathrm{d}F(\hat{\delta}_t|\bar{\eta}, \delta_t) \\ +\Pr(\eta_{t+1} = 0|\hat{s}_t, \delta_t, f_t, a_t, b_t)&\Big((1 - d_t)U_T^n(\hat{s}_t, 0, \hat{\delta}_t, f_t, a_t, b_t) \\ &+ d_t U_T^d(\hat{s}_t, 0, \hat{\delta}_t, f_t, a_t, b_t)\Big). \end{aligned}$$

(d) Finally, given these beginning of period values, we use the transition probabilities for $\hat{s}_{t+1}|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t$ to update our guess for the set of objects that determine convergence:

$$\begin{aligned} \Big\{&\mathbb{E}[V(\hat{s}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1}, \nu_{t+1})|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t], \\ &q(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1}), \\ &\Pr(\eta_{t+2}(\hat{s}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1}, \nu_{t+1}) > 0|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t), \\ &\mathbb{E}\left[\beta_c(1 + r)U_T(\hat{s}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1})|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t\right]\Big\}, \end{aligned}$$

where the price of debt is

$$q(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1}) = \frac{1}{1 + r}\mathbb{E}[Q(\hat{s}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1})|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t].$$

We calculate the distance in the sup norm between the updated objects and the guesses we started the iteration with. If the distance for each object is below a specified tolerance, we conclude the iterative process. If not, then we calculate the next guess for each of the relevant objects and return to step 2 of the process. Denoting each object by F, we set $F_{\text{next}} = \alpha_F * F_{\text{old}} + (1-\alpha_F) * F_{\text{updated}}$, where α_F is a object-specific smoothing factor.

Simulation. We now describe how we use the model solution obtained with the above algorithm to produce the main results of the paper. As described in the main text, these results are produced by feeding the measured sequence of exogenous variables into the model's policy functions. We refer to this process here as "simulation," because preference shocks introduce dispersion in model's outcomes for a given set of exogenous driving forces. We use the averaged model outcomes across preference shocks to calculate the model's prediction.[5] In our simulations, whenever a policy function or an initial value results in a b, a, or f taking a value off their respective grids, we randomly assign the value to one of the two adjacent grid points that bracket the value. The probability of reaching each of the two adjacent points is negatively related to the distance between the value and the grid point.

For our simulations, we generally need to determine optimal policies at values of the exogenous variables z_N, z_T, g_N, g_T, δ, and $\hat{\delta}$ that are not necessarily on the grids used for the computation of the solution, because the time series of exogenous variables were measured without restricting their values to lie on their grids. The problem is that our solution algorithm did not necessarily produce optimal policies for the particular values of the exogenous variables in the data. Forward-looking variables, such as the price of debt or the expected marginal utility of traded consumption, depend on the current value of any persistent exogenous state variable. Since exogenous variables in the time series are not necessarily on the grids used by our solution algorithm, our algorithm does not compute forward-looking variables at values that fall outside of the grid.

In order to address this problem, for each vector of exogenous variables, we compute a new set of forward-looking values that assume that, although the economy is off-grid in the current period, it will be on-grid in all future periods. Since our algorithm does compute on-grid values for all relevant outcomes from the next period forward, the only additional object that we need in order to calculate forward-looking values in the current period is the set of transition probabilities associated with the current, off-grid, exogenous state. For $\hat{\delta}$ and δ, we

[5] Whenever it might be necessary to draw a set of preference shocks in order to determine an optimal choice, we do not generate those preference shocks directly, but rather sample from the implied distribution of choices. This is without loss of generality, because we care only about the choices that arise because of the preference shocks, and not about their realized values.

set transition probabilities to their values at the nearest grid point in absolute value. For the remaining states z_N, z_T, g_N, g_T, we use the transition probabilities implied by the estimated parameters of the stochastic processes.

Even if there were no persistence in any exogenous variables, the exogenous variables would still affect the payoffs from choices made today, so optimal policies at off-grid points would in general differ from those our algorithm calculates for on-grid points. Here, we use the forward-looking values obtained by taking expected values using the transition probabilities we described above. Only a single iteration is required to compute these values because we are off-grid only in the current period.

This procedure allows us to generate a full set of policy functions for off-grid values of the exogenous state variables.[6] We use these policy functions, combined with the measured sequences of exogenous variables described in Appendix A, to generate our various simulations.

Adjusting the price of debt during restructuring and exclusion. To make the spread produced by our model comparable to the spread measured in the data, we make two overall adjustments throughout all simulations. First, because haircuts in the model are not actually applied until the transition from one period to the next, we calculate the spread in years when the government chooses to restructure as:

$$\text{spread}_t = \frac{\lambda_p + \kappa_p}{(1-\eta_{t+1})q(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1})} - \lambda_p - r. \tag{A.30}$$

This spread uses the model's ex-dividend price of the debt during the year leading up the actual application of the haircut and is therefore the model analogue of the data in such years.

Second, during periods of exclusion, in equation (A.30) we use the price of a marginal bond with the same maturity λ_p and coupon κ_p as those during the periods in which the country can access the international market. We call this price $\hat{q}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1})$, and it is calculated from the following fixed point problem:

$$\begin{aligned}\hat{Q}^d(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_t, a_t, b_t) = {} & (\hat{\lambda}_d(\eta_{t+1}, \hat{\delta}_t) + \hat{\kappa}_d(\eta_{t+1}, \hat{\delta}_t)) \\ & + (1-\eta_{t+1})(1-\hat{\lambda}_d(\eta_{t+1}, \hat{\delta}_t))\hat{q}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1}),\end{aligned}$$

[6] In order to improve the accuracy of these simulations, we also solve for these optimal policies on finer grids for b_t, a_t, and f_t than those used for the iterative solution. In particular, we use 61 points for b_t, 27 points for a_t, and 18 points for f_t. We leave the number of points for b_{t+1} fixed at 151.

$$\hat{q}(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1}) = \frac{1}{1+r}\mathbb{E}\Bigg[(1-d_{t+1})Q^n(\hat{s}_{t+1}, 0, \hat{\delta}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1})$$
$$+ d_{t+1}\mathbb{I}\{\eta^\star_{t+2} = \bar{\eta}\}\int Q^d(\hat{s}_{t+1}, \bar{\eta}, \hat{\delta}_{t+1}, f_{t+1}, a_{t+1}, b_{t+1})\mathrm{d}F(\hat{\delta}_{t+1}|\bar{\eta}, \delta_{t+1})$$
$$+ d_{t+1}\mathbb{I}\{\eta^\star_{t+2} = 0\}\hat{Q}^d(\hat{s}_{t+1}, 0, \delta_{t+1}, f_{t+1}, a_{t+1}, b_{t+1})|\hat{s}_t, \eta_{t+1}, \hat{\delta}_t\Bigg],$$

where $(\hat{\lambda}_d, \hat{\kappa}_d)(\eta_{t+1}, \hat{\delta}_t) = (\lambda_p, \kappa_p)$ when $\hat{\delta}_t > 0$ and both are 0 when $\hat{\delta}_t = 0$.

In addition to these overall changes, we make three other adjustments to the convention of the timing of the spread measurement to make the spread comparable to its data analog between 2010 and 2012. First, in 2010, we assume that foreign investors expect Greece to move in 2011 to the new regime with lower productivity, lower government spending, and higher tax rate, and so the price of debt reflects this new regime. Second, in 2011, we measure the spread after $\eta_{12} = \bar{\eta}$ has been chosen, but before the loan $\hat{\delta}$ is realized. This yields a expected value of the bond, inclusive of the dividend.[7] Third, in 2012, we measure the spread before the haircut is applied, since in the data the application of the haircut was effectively not complete until the end of the year. This means that in equation (A.30) we use the price of the debt from 2011.

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[7] We then obtain $\text{spread}_t = \left(\frac{(1-\lambda_p)(1-\bar{\eta})\mathbb{E}[q(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1})|\eta_{t+1}, \delta_t]}{(1-\bar{\eta})\mathbb{E}[q(\hat{s}_t, \eta_{t+1}, \hat{\delta}_t, f_{t+1}, a_{t+1}, b_{t+1})|\eta_{t+1}, \delta_t] - (\lambda_p + \kappa_p)} - 1\right) - r$.