ECB interventions in distressed sovereign debt markets: The case of Greek bonds

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Abstract

This paper analyses the determinants and effects of ECB interventions using bond-level data from Greece. We identify ECB purchases of individual Greek bonds using the fact that the ECB did *not* participate in the Greek debt exchange of March 2012, thus becoming a residual creditor and revealing its stock of holdings. In a first step, we provide new stylised facts on ECB bond buying activities and conclude that the ECB applied simple "rules of thumb" when intervening in the Greek market. Two variables alone (bond size and bond yields) can explain 70% of the large variation in ECB purchases across bonds. In a second step, we explore the short-term effects of ECB interventions in May and June 2010, a period of severe debt distress. We find that bonds bought by the ECB show a much larger drop in yields after the start of the SMP and that their yields also rebound much less in the weeks afterwards. Overall, our findings support the view that the interventions had a large "local" impact on the price of individual sovereign bonds and bond segments. This gives new support to theories with segmented and illiquid bond markets.

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1. Introduction

The ECB's "Securities Markets Programme" (SMP) was one of the largest and most controversial sovereign bond buying operations ever implemented by a central bank. It was also the precursor to the "Outright Monetary Transactions" (OMT) programme, which has been central to the ECB's strategy to resolve the Eurozone crisis since September 2012. Despite this, relatively little is known about the determinants and effects of ECB interventions in government bond markets, mainly due to a lack of publicly available data. Unlike the US Federal Reserve and the Bank of England, the ECB has remained opaque about its sovereign bond buying activities. The ECB did not reveal details on which bonds it bought, in what amounts, and when, so that researchers cannot easily assess the SMP and its effects.[2] This paper helps to fill this gap, by conducting the first bond-level analysis (to our knowledge) of ECB purchases in the Eurozone debt crisis.

The main innovation of this paper is to analyse ECB bond purchases at the level of individual bonds, which were revealed for one country, Greece, after the ECB decided not to participate in the Greek sovereign debt restructuring of 2012. Specifically, we got hold of a little-known, Greek-language government gazette which lists the ECB's holdings across all 81 Greek sovereign bonds outstanding in February 2012, just prior to the Greek bond exchange.[3] This data allows us to shed light, for the first time, on *how* the ECB intervened in distressed sovereign bond markets, in particular which Greek instruments it targeted (some purchases) and which it did not target (zero purchases). It also allows us to estimate the effect of ECB purchases on the yields of the targeted bonds.

Theory suggests two main channels through which the ECB purchases could have impacted bond yields. The first channel is variously referred to as a "portfolio balance", "preferred habitat" or "local supply" effect in the literature. Vayanos and Vila (2009) and Greenwood and Vayanos (forthcoming) suggest that investors can have a preference for particular bonds, e.g. because they are interested in a specific maturity. A change in bond supply can then result in a change in bond prices if financial frictions – such as risk aversion in a crisis period – introduce limits to arbitrage so that bonds are no longer perfectly substitutable by other assets. Central bank bond purchases could thus affect the yields in individual bonds or bond segments, as shown by D'Amico and King (2012) for the United States. The second channel through which ECB purchases could affect yields is by making bond markets more liquid. As a large buyer in a relatively illiquid market the ECB could have lowered the search costs of

[2] The ECB has only published data on weekly aggregate purchase amounts and, most recently, a snapshot of the country composition of the ECB's bond portfolio. See http://www.ecb.int/press/pr/date/2013/html/pr130221_1.en.html. For a survey comparing recent large scale bond purchase programmes across central banks, see IMF (2013).

[3] We are grateful to Sergi Lanau for pointing us to this source. Technically, the gazette shows the results of the "silent" ECB debt swap. On February 17 2012, all bonds held by the ECB and other central banks were exchanged into new bonds which were exactly the same as the old ones (same nominal amount, coupon payments, and repayment dates) but which were given a new set of serial numbers (ISINs).

finding a buyer, hence reducing liquidity premia of individual bonds or bond segments (see Duffie, Garleanu and Pedersen (2005, 2007) and De Pooter et al. (2013)). A third potential channel is less relevant in our context, namely the "signalling effect" of bond purchases on expected future short-term interest rates and inflation.[4] The SMP was designed to be neutral with respect to ECB's monetary policy and instead aimed at "restoring the functioning" of distressed sovereign bond markets in specific Eurozone countries.[5] As a result, one would not expect SMP purchases to affect yields via a change in expected future rates for the Eurozone as a whole. This is indeed consistent with our results.[6]

Several features make the ECB purchases of Greek bonds an excellent testing ground for theories on bond supply and liquidity shocks. First, the SMP resulted in a sudden shift in bond supply in a large fixed income market.[7] The ECB purchases were large and very concentrated. In total, more than €42.7 bnof Greek bonds were taken out of the market, which is 17% of the total Greek bond market in 2010. More than 70% of these purchases occurred in the first 8 weeks of the programme according to market sources (see section 2). At the same time, the amount of outstanding debt was essentially fixed since the Greek government was excluded from capital markets from April 2010 onwards. Second, the asset purchases took place during a time of severe market distress and with an imminent risk of a Greek default. In such an environment, with low liquidity and risky arbitrage, bond supply shocks can be expected to have particularly large effects, at least from a theoretical perspective. The question is whether this was indeed the case, and how large the effects were.

The first contribution of this paper is to provide a unique insight into the design of the SMP and its bond buying patterns in the case of Greece. We show that purchases varied greatly across the 81 Greek bonds: the ECB bought up to 38% in some series (of total principal outstanding), while 51 bonds were not bought at all. The ECB favoured large benchmark bonds with a remaining maturity of less than 10 years, as well as bonds with comparatively high yields. Foreign-law bonds were not targeted, and neither were bonds not priced on Bloomberg. We conclude that the ECB appears to have applied simple "rules of thumb" when choosing which bonds to buy. Two variables alone - bond size and bond yields - explain 70% of the variation in ECB purchases.

Our second contribution is to analyse the effects of ECB intervention on yields of *individual* Greek bonds. We focus on the first phase of the SMP, May and June 2010, when most purchases of Greek bonds were undertaken. Identification comes from the cross-sectional

[4] On the role of the signalling channel see Eggertsson and Woodford (2003) and Bauer and Rudebusch (2013).
[5] This is clear both from statements by ECB official (e.g. speech by José González-Páramo: http://www.ecb.int/press/key/date/2011/html/sp111125.en.html, emphasising that the SMP did *not* constitute quantitative easing) and also by the fact that the liquidity effects of ECB were sterilised.
[6] We find that the results are nearly identical when using yield spreads above German Bunds instead of plain yields.
[7] As of 2010, Greece was among the 15 largest sovereign bond markets worldwide.

variation in ECB purchases since we can compare the changes in yields between intervened bonds and bonds that were not targeted by the ECB. This helps to isolate the effect of purchases from news and other factors that might have influenced bond yields during the intervention period. Simple yield charts suggest a large effect of ECB purchases and this picture is confirmed through cross-sectional regressions using yield changes as dependent variable. To deal with endogeneity and selection effects – in particular the possibility that the ECB targeted underpriced bonds – we control for pre-SMP yields. We also run two-stage least squares regressions, using bond characteristics that are correlated with ECB intervention (but not bond prices) as instruments. In a last step, we adopt a difference-in-difference type estimation to account for unobserved bond characteristics.

According to our most conservative model, a purchase of 10 per cent of a Greek bond series is associated with a yield drop of 100-150 basis points in that series during the 8 weeks following the start of the SMP, after controlling for changes in bond-specific default risk (proxied by changes in CDS prices at various maturities), differences in legal risk (proxied by governing law), pre-SMP bond yields, and purchases of bonds of similar maturity. An additional €1 bnof purchases had a yield impact of 160 to 204 basis points in that bond. Based on these results, we estimate that the total drop in yields attributable to the ECB purchases was between 177 and 226 basis points – abstracting from any effect that the SMP may have had on perceived Greek default risk or perceived lossgivendefault (LGD).[8] The findings are similar for various time frames: 1 week, 4 weeks or 8 weeks; and even just after the first day of the SMP, May 10 2010, on which large SMP interventions took place.

We find the effects to be particularly pronounced at the short end of the yield curve (years 1 to 5). The Greek yield curve turned from downward sloping to well-behaved in a matter of days, and this remarkable twist in the yield curve is closely related to the volume of ECB interventions in each term structure segment. These findings help to rationalise the design of the SMPs successor programme, the OMT, which targets shorter maturities where interventions appear to be most effective in crisis times.[9]

The paper forms part of an incipient literature on the effects of central bank asset purchases, which so far has mostly focused on the Large Scale Asset Purchase Programmes (LSAP) by the Federal Reserve Bank and the quantitative easing (QE) programmes by the Bank of England.[10] Our approach is closest to D'Amico and King (2013) for the US and Joyce and

[8] This compares to a total impact of about 30-50 basis for the first LSAP programme of the Federal Reserve, according to D'Amico and King (2013), and approximately matches the announcement effect of QE in the UK, according to Joyce and Tong (2012). See IMF (2013) for a comparison of the impact of bond purchase programmes in a number of countries.

[9] The OMT programme will focus, in particular, "on sovereign bonds with a maturity of between one and three years." http://www.ecb.int/press/pr/date/2012/html/pr120906_1.en.html

[10] The impact of the Federal Reserve's LSAP is analysed in Gagnon et al. (2010), Krishnamurthy and Vissing-Jorgensen (2011), Bauer and Rudebusch (2012), D'Amico et al. (2012), Hamilton and Wu (2012), Cahill et al. (2013) and D'Amico and King (2013). For evidence on the UK's QE, see Joyce et al. (2011) and Joyce and

Tong (2012) for the UK, who both exploit bond level data to identify the effect of bond purchases. Compared to these papers, we find much larger effects in the Greek crisis context. Given the more severe crisis setting, this is consistent with the above mentioned theories of limited arbitrage and risk aversion, and also with the idea that interventions will be more effective in less liquid markets, such as in Greece of mid-2010 (see Gürkaynak and Wright (2012) for a discussion).

Regarding ECB interventions in sovereign bond markets, we are aware of only two contributionsthat are written in parallel with the present paper, namely Eser and Schwaab (2013) and De Pooter et al. (2013). Both use panel regressions with country fixed effects to estimate the effect of intervention at the country (rather than bond) level. Eser and Schwaab (2013) use the yield of a 5-year benchmark bond as dependent variable as well as confidential ECB data on daily purchase amounts by country. De Pooter et al. (2012) use weekly estimates on the amount of SMP purchases from JP Morgan and focus on the effect on liquidity premia of 5-year bonds, which they proxy by the difference between implied default probabilities in CDS and bond spreads. Our paper differs from these analyses in that we use bond-level data and exploit the cross-sectional variation between intervened and non-intervened bonds. This helps to disentangle purchase effects from potentially confounding factors such as news shocks. It also allows us to illustrate the impact of intervention graphically – via yield curve plots and by comparing yield time series of bonds with and without intervention. Unlike Eser and Schwaab (2013) or De Pooter et al. (2013), our approach leads to an estimate of the "local" effect of central bank interventions, which reveals stark differences across types of bonds and maturities. In addition, our paper is the first to shed light on the determinants of ECB bond buying, and not only on its effects. This facilitates a more informed discussion about the opaque SMP.

The section that follows describes the SMP and presents our bond-level data. We next present new stylised facts on ECB purchasing patterns in the case of Greece. Finally, we turn to the effects of intervention, beginning with a graphical analysis of the data.

2. Data and context

This section briefly describes the ECB's Securities Markets Programme and our strategy to identify the stock of Greek bonds held by the ECB in February 2012.

2.1 The ECB Securities Markets Programme

The SMP was announced on Sunday May 9, 2010 and officially activated one day later. The (largely unexpected) inception of the programme followed an escalation of the Eurozone debt crisis in late April and early May, with widening yield spreads across the Eurozone

Tong (2012). More general papers on the relation of bond prices and bond supply include Bernanke et al. (2004), Greenwood and Vayanos (2010, forthcoming), and Krishnamurthy and Vissing-Jorgensen (2012),

periphery, in particular in Greece, Portugal, and Ireland. On May 10, the ECB released an official statement announcing the programme. Further details were published on May 14, in particular on the type of instruments eligible for purchases under the programme, including Euro denominated bonds issued by central governments and public entities of Eurozone Member States.[11]

There were two main phases of SMP activism. We focus on the first 8 weeks of interventions, which lasted from the inception of the programme, on May 10, until early July of 2010. According to market consensus, bond purchases in this phase focused on Greek, Irish, and Portuguese debt.[12] The programme effectively came to a halt in the following twelve months, with little or no purchases. However, on August 7 2011, the ECB announced a reactivation of the SMP, giving rise to the second phase of bond purchases, which lasted until December 2011.[13] It is widely believed that the ECB mainly purchased Spanish and Italian bonds in this period.[14] Interventions were larger than before and the ECB tripled its stock of holdings from €70 bn to over €200 bn (at market prices). The programme officially ended in September 2012 with the introduction of a successor programme, the OMT, which has not been activated yet. Figure A1 in the Appendix shows the timeline of aggregate weekly SMP purchases from May 2010 until 2012 (at market prices, not face value), as well as the total stock of bonds held, as reported by the ECB.

There are several important differences between the ECB's SMP and the bond purchase programmes in the US and the UK:

- *The SMP's objective* was to contain the debt crisis in specific Eurozone countries, not to ease monetary conditions in the Eurozone. This stands in contrast to the QE programmes of the Federal Reserves and the Bank of England which where a tool for monetary expansion with the aim to lower long-term interest rates. Officially, the SMP's purpose was to restore the appropriate transmission of monetary policy and "to ensure depth and liquidity in those market segments which are dysfunctional".[15] ECB board members repeatedly emphasised that all bond purchases would be sterilised.
- *SMP purchases were highly concentrated*, taking place mostly in weeks with severe distress. In Greece, the bulk of purchases occurred in May and June 2010 (see below). For Italy and Spain, more than half of all SMP bond purchases are estimated

[11] For details, see http://www.ecb.int/ecb/legal/pdf/l_12420100520en00080009.pdf
[12] See e.g. http://ftalphaville.ft.com/blog/2010/12/13/434886/the-peripheral-bond-buyer-of-last-resort/
[13] See "Statement by the President of the ECB" from 7 August 2011 http://www.ecb.europa.eu/press/pr/date/2011/html/pr110807.en.html
[14] See http://www.ecb.int/press/pr/date/2011/html/pr110807.en.html (BB: same link as above), and market rumours, e.g. Wall Street Journal, August 8 2011 "ECB Buys Italian, Spanish Bonds", or http://www.zerohedge.com/news/ecb-purchases-%E2%82%AC22-billion-italian-spanish-bonds-past-week-highest-weekly-amount-ever.
[15] http://www.ecb.int/press/pr/date/2010/html/pr100510.en.html

to have occurred between mid-August and mid-September 2011 (Barclays 2012). This stands in contrast to the programmes to the US and the UK, where purchases were also large[16], but much more spread out over time.

- *The ECB remained opaque about its purchases.* The SMP was announced as an open-ended operation without clear targets. The ECB set no time frame and no upper or lower limits to its interventions. It did not reveal which sovereign bonds it purchased and when and in what amounts they were purchased, not even at the countrylevel. Interventions were difficult to predict, by buying bonds in the (non-anonymous) dealer market, so that investors could only learn from those transactions they were able to observe. This differs from the LSAP and QE programmes, which were much more transparent and which were implemented via regular auctions.
- *The SMP did not sell bonds.* The ECB committed to a policy of holding the bonds it bought until maturity, unlike the central banks of England or the US.[17] Figure A2 shows that the size of the SMP portfolio grows in line with the weekly purchase amounts. Any decrease in the stock of holdings is due to maturing securities and not due to bond sales.

2.2. The Greek sovereign debt restructuring of 2012

To identify the bonds bought by the ECB we take advantage of the historic Greek sovereign debt restructuring, which was implemented between February and April of 2012. The operation was the largest sovereign bond exchange in history and restructured all outstanding Greek government bonds owed to private creditors, namely 81 Hellenic Republic titles with an eligible volume of €195.7 bn (see Zettelmeyer et al.(2013) for a detailed description).[18]

For the purposes of this paper, the essential feature of the Greek debt exchange is that the ECB did *not* participate in it. Technically, the exemption took the form of a "silent" debt swap: between February 17 and February 21 2012, all bonds held by the ECB and other Eurosystem central banks were exchanged into new bonds which were exactly the same as the old ones (same nominal amount, coupon payments and repayment dates) but had different serial numbers (ISINs). The instruments involved in this "silent" swap were not eligible in the Greek debt restructuring proposal of February 24 2012. The old bonds (with original ISINs) were exempt because they had been transferred to Greece in the swap and

[16] As a share of outstanding bonds, the Greek SMP purchases were larger than the Federal Reserve's first (March-October 2009) large-scale asset purchase (LSAP) programme ($300 bn, representing just 3 per cent of total outstanding Treasury debt and 8 per cent of outstanding coupon securities) but smaller than the UK's first (March 2009 to January 2010) quantitative easing programme (£200 nb, or about 30 per cent of UK gilts outstanding at the time.

[17] In a related Q&A in February 2012, ECB president Draghi reconfirmed this as follows: "Question: Will you hold the bonds in your SMP programme until maturity? Draghi: We have no reason to change this commitment. If we do, we will tell you." http://www.ecb.int/press/pressconf/2012/html/is120209.en.html

[18] In addition, the exchange involved 36 instruments issued by three public entities: Hellenic Railways, Hellenic Defence Systems, and Athens Urban Transport Organisation ("guaranteed titles"), with a volume of €9.8 bn. Here, these quasi-sovereign bonds are excluded, mainly because these were not bought via the SMP.

were subsequently cancelled (see the offering memorandum, p. 15). The new, central bank owned ones (with new ISINs) were exempt because the debt restructuring offer only targeted bonds issued "prior to 31 December 2011", thus excluding those issued in the February 17 swap. With this simple operation the ECB, national central banks (NCBs), and the European Investment Bank (EIB) avoided taking a haircut and made their bonds disappear from the stock of tradable Greek debt.

2.3. Data on ECB bond purchases

The data on ECB bond purchases used in this paper was published in a Greek-language government gazette in February 2012, which is available in printed form only. Specifically, we draw on the government gazette issues "413 V/2012", "574 V/2012", and "705 V/2012". These issues list the amount of each bond swapped by the ECB, the Eurozone NCBs and the EIB, respectively, and hence their holding portfolios as of February 2012.

In total, the ECB holdings sum up to €42.7 bn, which was 17% of the total stock of Greek sovereign bonds in February 2012. Because the ECB had a buy-and-hold portfolio, this stock of holdings reflects the cumulative amount purchased via the SMP between May 2010 and February 2012, minus purchases of bonds that matured between May 2010 and February 2012. National Central Banks held another €13.5 bn (7% of total), while the European Investment Bank held €315 mn.

We check the reliability of this information in two ways. First, we compare the sum of holdings from the gazettes to the total figure published in the official Greek debt exchange memorandum of March 2012. The memorandum explicitly states that €56.5 bn "were acquired by the European Central Bank and certain National Central Banks prior to 22 February 2012" (p. 15). This figure is identical to the sum of the gazette-based holdings data of the ECB (€42.7 bn), NCBs (€13.5 bn), and EIB (€315 mn). Second, we compare for each bond the amount of private sector holdings eligible for the exchange (from the Greek bond exchange memoranda) to the total principal amount outstanding of that bond in February (from Bloomberg). The residual is equivalent to the amount held by non-private creditors, i.e. the total holdings by the exempt ECB, NCBs, and the EIB. Again, we find the information to be coherent. The big advantage of using the gazette information is that it allows us to distinguish ECB holdings (purchased via the SMP) from other central bank holdings (by the NCBs) as well as from EIB holdings, so that we gain new cross-sectional insights. Figure 1 illustrates the distribution of Greek government bond holdings across types of creditors (in February 2012).

[Figure 1 about here]

The main limitation of our data is that it is available for only one point in time (February 2012). We do not know the purchase dates and we have no information on SMP purchases, if

any, of bonds maturing prior to February 2012.[19] Despite this, we can make reasonable assumptions on the main purchase periods based on total ECB purchase data and additional information from market dealers and the financial press. Indeed, all available evidence suggests that the large majority of Greek bonds were purchased in the first few weeks of the SMP. Figure A2 shows detailed weekly estimates from Barclays (2012), a major dealer in Greek bonds , whose estimates are also used in the regressions by De Pooter et al. (2013).

The Barclays estimates for Greece roughly correspond to several news and analyst reports at the time. For example, in early June 2010, three weeks after the programme start, the Wall Street Journal reported that the ECB had already "spent about €25 bn on Greek debt according to a senior Bundesbank official who declined to be named", while Der Spiegel reported that "the ECB already has about €25 bn of Greece's mountain of debt on its books, and it is adding another €2 bn a day, on average."[20] These figures are very similar to the Barclays estimate of Greek bond purchases in May 2010, namely €22 bn at secondary market prices or more than €26 bn at face value (at an average price discount of 15%, and including maturing bonds between mid-2010 and early 2012). This would mean that more than 50% of all Greek bonds in the ECB portfolio were bought in the first three weeks of the SMP.

For our main period of analysis, from May 10 to July 5, Barclays estimates a total amount of Greek bond purchases of €35 bn at market prices, or roughly €41 bn at face value. This implies that more than 75% of total SMP purchases of Greek bonds occurred in the first 8 weeks (after May 10). Taken together, we therefore conclude that the ECB holdings of February 2012 are a useful proxy for Greek SMP bond purchases in May and June 2010.

3. Determinants of ECB purchases

This section takes a first look at the data and provides new stylised facts on the determinants of ECB bond buying in crisis times. We focus on the cross-section of all Greek government bonds that were outstanding just prior to the Greek debt exchange, and compute the share of each bond held by the ECB as a percentage of total amount outstanding (both in February 2012). To do so, we draw on data from Bloomberg and the dataset collected by Zettelmeyer et al. (2013), which provides additional information on main bond characteristics, such as issuance date, maturity, coupon size or governing laws.

The data shows a substantial variation of ECB holdings across the 81 Greek bonds. Table A1 in the Appendix shows that the ECB bought substantial amounts of some bond series (up to 38% of total outstanding) but did not purchase a single bond in most other series. Indeed, 51 out of the 81 Greek bonds show zero ECB holdings, so that all purchases occurred in a subsample of 30 bonds only. The mean share of ECB holdings was 6.8%, with a median of

[19] Matured bonds are therefore not part of our analysis.
[20] See WSJ, June 1 2010, "Bundesbank Attacks ECB Bond-Buying Plan" and Der Spiegel, May 31 2010, "ECB Buying Up Greek Bonds: German Central Bankers Suspect French Intrigue".

0% and a standard deviation of 11.5 percentage points. Figure 2 illustrates the sizable variation in holdings for the subsample of the 20 largest Greek bonds (ranked by face value outstanding).

[Figure 2 about here]

What explains this variation? What criteria did the ECB apply when choosing which bonds to purchase? Table 1 provides a first overview, by comparing the SMP portfolio of Greek bonds with the full sample of 81 Greek bonds, both weighted by bond size.

The table shows that:

(i) *The ECB only bought Greek law bonds* (99.9% of holdings).[21] That is, it shied away from sovereign bonds issued under English, Italian or Japanese law, despite the fact that 28 out of the 81 instruments were foreign law bonds (7.4% of total amount outstanding).

(ii) *The ECB only bought bonds that were regularly priced* on standard platforms such as Bloomberg. We find that pricing data was available for only 42 of the 81 Greek government bonds. These 42 traded bonds account for €42.7 bn, or 99.9% of total ECB holdings. The ECB clearly shunned bonds which were not visible in secondary markets.

(iii) *The ECB focused on large, relatively liquid benchmark bonds.* 95% of the bonds held by the ECB are benchmark bonds, defined as those bonds that have been used at least once for computing the Greek yield curve on Bloomberg (we considered Bloomberg yield curve data back to the year 2000). This compares to 75% of bonds in the full sample. A further look at the data clearly confirms that the ECB had a preference for large, liquid bonds. The 20 largest bonds listed in Figure 2 account for over 80% of ECB holdings (compared to 75% of the full sample). Also the bid-ask spread data available to us indicates that the ECB was more likely to buy relatively more liquid bonds.[22]

(iv) *The ECB focused on bonds with shorter and medium maturities.* The average maturity of the Greek ECB portfolio was just 5.4 years, compared to more than 9 years in the full sample of Greek bonds (Euro-weighted and measured as of May 2010). Figure 3 shows the maturity distribution of the Greek ECB portfolio in more

[21] The exception was one English law bond maturing in 2014, of which the ECB held a small amount.
[22] For a quick assessment, we use 30-day average bid-ask spreads in the period prior to the start of the SMP (i.e. before May 10). However, the bid-ask spread data in Bloomberg should be taken with care (see section 4.1.).

detail. The chart confirms that the ECB had a preference for shorter-dated instruments and did not buy long-dated bonds of more than 20 years maturity.[23]

[Figure 3 about here]

(v) *The ECB had a preference for bonds with higher yields.* To show this, we construct 4-week average yields for the pre-SMP period (i.e. from April 12 until May 7, using those bonds with uninterrupted pricing data (from Bloomberg). Table 1 shows that the average pre-SMP yield of bonds in the ECB portfolio was 10%, compared to 9% in the full sample. Figure 4 further illustrates the close relationship between ECB holdings (in per cent of total face value) and bond yields. The figure looks very similar when using plain yield spreads above German Bunds, when using the amount purchased in € bn instead of the share bought, or when using the increase in yield spreads between April 12 and May 7, instead of yield levels. We can therefore conclude that bonds with higher yields or yield spreads (pre-SMP) were more likely to be bought by the ECB.

[Figure 4 about here]

This last finding relates to one of the most controversial issues of the ECB's bond market interventions, namely whether it should intervene with the explicit aim of lowering yield spreads. For example, in an interview in November 2011, Bundesbank president Jens Weidman underlined that "the stated purpose of the SMP is to cope with dysfunctional markets and it's not to ensure a specific spread for a specific country." [24] Our findings suggest that yields (and yield spreads) might have played a significant role for the selection of bonds targeted by the SMP. Of course, this is still consistent with the view that the ECB was not targeting a *specific* level of spreads.

To assess the determinants of ECB bond buying more systematically, we run OLS regressions using as dependent variable the amount of bond purchases as a percentage of total par value outstanding of each bond. As a robustness check, we also use the total amounts purchased in € bn and run a probit regression using an ECB target dummy (capturing any purchases) as dependent variable, with similar findings.

In Table 3, we start with the full sample of 81 bonds and focus on time-fixed bond characteristics such as the outstanding amount, coupon, maturity, and governing law (see Table 2 for a description of each variable). It is remarkable that a dummy variable capturing benchmark bonds – or alternatively, bond size ("volume outstanding") – can explain nearly

[23] This preference for short-term bonds will be even more pronounced in any future interventions. In September 2012, the ECB announced that the OMT will focus on "sovereign bonds with a maturity of between one and three years." See http://www.ecb.int/press/pr/date/2012/html/pr120906_1.en.html (BB: does this link work?)
[24] See http://www.ft.com/intl/cms/s/0/b3a2d19e-0de4-11e1-9d40-00144feabdc0.html (BB: requires account)

half of the variation in bond buying patterns of the ECB, with an R^2 of almost 50%. The coefficients are also quantitatively large. Column (6) shows that, when controlling for other bond characteristics, benchmark bonds are associated with an 8 percentage points higher share of ECB holdings, which is larger than the mean share of ECB holdings (6.8%). A one standard deviation increase in bonds size (by €4.1 bn) is associated with an increase in ECB holdings of 5 percentage points. Bond maturity and coupon size also have statistically significant effects, but can explain only a small fraction in the variation of ECB holdings.

[Table 2 about here]

Columns (7) to (9) extend the baseline regressions by adding pre-SMP bond yields, using averages for the four weeks from April 12 until May 7 2010. In line with Figure 4, we find that bond yields are highly correlated with central bank purchases, with an R^2 of 68% (column (7)). Controlling for other bond characteristics, a 1 percentage point higher yield is associated with a 2 percentage point increase in ECB holdings of a bond (column (9)). These results are very similar when using yield spreads (above German Bunds), or when using the percentage point increase in bond yields between April 12 and May 7, 2010 (instead of the average of that period).

Taken together, ECB bond buying patterns appear to be fairly predictable, at least in the case of Greece. Just a few variables, in particular the benchmark bond dummy, coupon size, and pre-SMP bond yields, explain up to 80 per cent of the SMP portfolio composition of Greek bonds.

4. The effect of bond purchases on yields

This section assesses the effects of ECB bond purchases on Greek sovereign bond yields. As in D'Amico and King (2013), our main focus is on comparing changes in yields of bonds that were purchased by the central bank with yield changes of bonds that were not purchased. We focus on the 8 weeks between May 10 and July 5 2010, the first wave of ECB activism. Estimates suggest that 70 to 80% of all Greek bonds in the SMP portfolio were bought in this period (see section 2.3. and Appendix A1 and A2).[25]

4.1. A first look at the data

We start with a graphical assessment of the data. Our main source on yield data of individual bonds is Bloomberg, which combines information from more than a dozen dealers and therefore provides the most reliable Greek bond price information. We checked the data quality by comparing it with other sources such as JP Morgan, a major dealer in the Greek bond market, but found the Bloomberg data to be significantly more complete and less

[25] The ECB's LTRO facility was initiated much later, in late 2011.

noisy.[26] Unfortunately, we were not (yet) able to gather reliable bond-level data on liquidity measures such as bid-ask spreads or bond turnover.[27] However, to avoid bias, we drop obviously illiquid bonds for which no regular pricing data was available.

Specifically, we drop 5 out of the total 42 bonds that were trading on secondary markets, resulting in a final yield sample of 37 bonds. Sample selection bias should not be a major concern since the ECB barely bought bonds that were not regularly traded (see above). Indeed, our final yield sample of 37 bonds accounts for 99.5% of total ECB purchases. More precisely, 24 bonds in our main sample were targeted (some SMP purchases) and 13 were not targeted (no SMP purchases).

Figure 6 shows a close correlation between the share of each bond bought by the ECB and the change in yield spreads between May 7 and May 17, the first week after the SMP was introduced (left chart) as well as over the entire 8-week intervention period (right chart). The higher the amount purchased of each bond, the stronger the decrease in yields. The slope coefficient is about -0.3 in the left chart and -0.25 in the right one, i.e. a 250 basis point drop for bonds for which the ECB purchased a 10 per cent share. The correlation coefficient between ECB purchases and yield changes is slightly tighter for the 8-week period (-0.91 compared to -0.89 for the 1-week period), which may reflect the fact that the ECB stock data is likely to capture actual bond purchases over the entire 8-week period more accurately than the first week purchases. Note also that for bonds in which the ECB did not intervene (points circled by a zero number) yield changes were not significantly different from zero either after the first week or over the 8-week period, reflecting the evaporation of the ECB announcement effect during the first few days and the onset of market scepticism about the Greek programme.

Figure 7 shows the drastic change in the Greek bond yield curve before and after the start of the SMP. On May 7, the last Friday before the programme, the curve shows the typical downward-sloping shape of a sovereign with high default risk (Cruces et al. 2002, Arellano and Ramanarayanan 2012). Once the SMP interventions started, however, the curve becomes "well-behaved", that is upward sloping and slightly concave, albeit at a high level. The shift is most pronounced in those maturity segments in which the ECB intervened most, namely in the short and mediumterm. This is evident from the size of the circles, which reflect the amount of ECB purchases in each bond (in € bn), as well as in the numbers shown, which represent the total share of ECB purchases in that series (in %). The bond curve clearly moves most where circle sizes and figures are largest, i.e. at maturity of less than 10 years.

[26] According to the Bloomberg Help Desk this is not due to artificial or interpolated data. The yield information seems to be solely based on actual market prices.
[27] Turnover data is not readily available on Bloomberg. Moreover, the bid-ask spread data can contain interpolated/estimated values and do not necessarily show actual bid-ask spreads by bond dealers.

The speed at which the yield curve twisted is partly attributable to the intensity of ECB interventions in the first week of the programme (see Appendix). Barclays (2012) estimates that in just 5 days €9 bn in Greek bonds were purchased under the SMP at market value (including large purchases on the first day, May 10). This estimated amount of purchases in the first week corresponds to nearly 5% of the entire stock of Greek sovereign bonds, a drastic supply shock.

It is worth comparing the dynamics of the bond yield curve to those of the CDS yield curve, which picks up ”pure” default risk at different maturities of Greek CDS contracts (based on data by JP Morgan). Figure 8 shows that the CDS premia also feature a stark drop after the SMP announcement of May 9 and the simultaneous news on the creation of the €750 bn European Financial Stability Fund (EFSF) (which was announced on the same day). But the effects are much less pronounced at the short end of the curve. Compared to the bond yield curve in Figure 7, the CDS curve of Figure 8 does not “twist” into an upward-sloping shape. Instead, the curve remains inverted throughout the entire first wave of SMP bond buying in May and June of 2010. One explanation for these notable differences is that the ECB did not directly intervene in CDS markets, so that prices are affected only by the SMP announcement and other crisis-related news, rather than by intervention in the sovereign bond market itself.

We next look at the data in a time series dimension. For this purpose, we divide Greek instruments into “targeted” and “non-targeted” bonds, where “targeted” is defined as ECB holdings above 0, while “non-targeted“ are those which the ECB did not touch at all. Figure 9 shows the (€-weighted) average yields of targeted vs. non-targeted bonds during, before, and after the first period of SMP interventions. It is apparent that the yields of targeted bonds bought by the ECB dropped much more than those of non-targeted bonds. The yields of non-targeted bonds also rebound much quicker after the first announcement effect on May 10 and quickly reach pre-SMP levels. The yield of targeted bonds, in contrast, stay at their post-announcement level, on average, and only start to increase again when the total volume of ECB interventions decreases notably (after mid-June 2010).

A similar picture arises when we compare yield time series of individual bonds with and without intervention. The upper panel of Figure 10 compares the yields of a targeted 2024 Greek-law bond with a high 4.7% coupon (of which the ECB bought 10.4%) to those of a non-targeted 2025 Greek-law bond with a floating interest rate of 2.9% above the Eurozone HICP inflation rate (which the ECB did not buy). The yield premium between these two bonds disappears after the start of ECB bond buying (May 9), but reappears again after interventions end in early July 2010. A similar, albeit less pronounced, pattern is visible in the lower panel of Figure 10, which compares a 2020 bond of which the ECB bought 22% to a 2022 bonds of which the ECB bought only 6%. Figures 9 and 10 thus confirm the impression of the cross-sectional figures above: the price increases during the period of interventions were particularly large in those bonds that were bought by the ECB.

4.2. Identifying the effect of bond purchases

Beyond graphical analysis, we wish to test for the presence of an ECB intervention effect and estimate its magnitude. Doing so poses a number of identification challenges.

To organise the discussion, it is useful to start from the generic model used in papers such as D'Amico and King (2013) and Joyce and Tong (2012) to test for bond purchase effects using bond-by-bond data, written as:

$$(1)\ \Delta y_i = \gamma q_i + \Phi(\tau_i) + \varepsilon_i$$

where Δy_i denotes the change in the yield of bond i over the intervention period, q_i the normalised purchase amount, τ_i the remaining maturity of bond i, $\Phi(.)$ a smooth function of maturity (for example, a quadratic), and ε_i an error term.[28] D'Amico and King (2013) show that (1) can be justified using a Vayanos and Vila-type model generating local supply effects. Since all terms in equation (1) are observable, it can in principle be estimated using OLS or two-stage least squares (if endogeneity of q_i is a concern, for example because of the way in which the central bank may be deciding on purchase amounts).

Equation (1) does not explicitly model the effect of expectations on bond purchases. However, this may be important both to interpret the coefficient estimates in model (1) and to understand potential sources of misspecification before the model is taken to the data. As a benchmark, consider a bond purchase programme of fixed duration and pre-announced purchase amounts, such as the Federal Reserve's first LSAP between March and October of 2009. Suppose equation (1) refers to changes in bond yields over the entire programme period (this is referred to as the "stock effect" by D'Amico and King (2013)). Allowing for the possibility that the LSAP was partly anticipated, one can write down a generalisation of equation (1):

$$(2)\ \Delta y_i = \beta[q_i - E_0(q_i)] + \theta q_i + \Phi(\tau_i) + \varepsilon_i$$

Where $E_0(q_i)$ refers to any expectation of bond purchases *prior* to programme announcement, the coefficient β represents expectations effects, and θ captures any additional direct purchase effects under the programme. If the programme was not fully anticipated, $q_i > E_0(q_i)$.

[28] This equation ignores the effect of purchases of "close substitute" bonds (meaning bonds of similar maturities) on Δy_i (see D'Amico and King(2013)). This is not essential for the discussion that follows, and also turns out to be less empirically relevant in the context of the SMP than in the context of quantitative easing. We consider the effects of close substitutes in a robustness analysis below.

If one decomposes $E_0(q_i)$, into its mean and deviation from the mean, denoted $\bar{E}_0$ and $\tilde{E}_{0,i}$, respectively, equation (2) can be rewritten as:

$$(3)\ \Delta y_i = -\beta\bar{E}_0 + (\beta + \theta)q_i + \Phi(\tau_i) - \beta\tilde{E}_{0,i} + \varepsilon_i$$

Comparing (1) and (3), it is clear that if equation (1) is run with a regression constant when (3) is the true model, the regression constant would absorb the mean $\bar{E}_0$ across bonds, while deviations from the mean would be absorbed by the error term (or, in case of maturity specific effects, by $\Phi(\tau_i)$). If $\tilde{E}_{0,i}$ is correlated with actual intervention, q_i, this might complicate the estimation. However, it is clear that consistent coefficient estimates of γ (e.g. using 2SLS) would pick up $\beta + \theta$, i.e. the total effect of intervention. Hence, as pointed out by D'Amico and King (2013), the crucial advantage of cross-sectional estimation in this context is that it identifies the *total* effect of LSAP-type bond purchase programmes, even if these purchases were partly anticipated. This is not true for event studies or other approaches that rely on time-series variation, since expectation effects can potentially bias the estimated purchase effects that result from a comparison of yields before and after intervention.

Consider now the SMP purchases of Greek bonds during May and July 2010. In this context, the framework needs to be extended for two reasons:

(i) First, actual purchases under the SMP were not made public, and were not easy for the private sector to identify. Although interventions happened in the non-anonymous dealer market, the bond market at best picked up a noisy signal – and estimate – of the interventions that had actually occurred.

(ii) Moreover, the SMP was open-ended, with market uncertainty whether and how long central bank purchases would go on. No termination date was announced by the ECB and no purchase amounts or auction calendar were set in advance. For this reason there was no way for the private sector to tell how much was "left" under the programme during the May-July intervention period we are considering. It is thus likely that prices at the end of the intervention period embody expectations of *future* bond purchases. These expectation effects are even more relevant, of course, if we run regressions for shorter periods – e.g. for the first week or first 4 weeks after May 9, when large scale purchases were still ongoing.

To reflect these facts, equation (2) can be generalised as follows:

$$(2')\ \Delta y_i = \beta[\sigma(q_i) - E_0(q_i)] + \theta q_i + \Phi(\tau_i) + \delta\left[E_1\left(q_i^f\right) - E_0\left(q_i^f\right)\right] + \varepsilon_i$$

where $\sigma(q_i)$ denotes *perceived* purchases during the intervention period (a noisy signal of q_i), and $E_1\left(q_i^f\right) - E_0\left(q_i^f\right)$ denotes any expectations surprise with respect to *future* purchases which might have occurred during intervention period. Decomposing $\sigma(q_i), E_0(q_i)$, and

$E_1(q_i^f)$ and $E_0(q_i^f)$ into means and deviations of means as before – denoted $\bar{\sigma}$, $\bar{E}_0$, $\bar{E}_1^f$ and $\bar{E}_0^f$, and $\tilde{\sigma}_i$, $\tilde{E}_{0,i}$, $\tilde{E}_{1,i}^f$ and $\tilde{E}_{0,i}^f$, respectively – this can be rewritten as:

$$(3') \; \Delta y_i = \alpha + \theta q_i + \Phi(\tau_i) + \mu_i$$

where $\alpha \equiv \beta\left[\bar{\sigma} - \bar{E}_0\right] + \delta\left[\bar{E}_1^f - \bar{E}_0^f\right]$ and $\mu_i \equiv \beta\left[\tilde{\sigma}_i - \tilde{E}_{0,i}\right] + \delta\left[\tilde{E}_{1,i}^f - \tilde{E}_{0,i}^f\right]_{1,i}^f + \varepsilon_i$

Suppose now that we run regression (1), i.e. a cross-sectional regression of Δy_i on bond purchases and bond maturities. Comparing models $(1), (3')$,and (3), it is clear that depending on whether $(3')$ or (3) is the true model a consistent estimate of the coefficient γ (the coefficient on bond purchases in the estimated model (1)) will identify different parameters. In the LSAP setting – i.e. if (3) is the true model – the estimated coefficient on bond purchases should identify the total effect of intervention $(\beta + \theta)$. In contrast, in the SMP setting – if $(3')$ is the true model – the coefficient for bond purchases should measure only the direct purchase effect θ. The announcement effect and any surprises about the ECB's bond buying patterns during May-July 2010 would thus be captured in the regression constant α and – in case of maturity-specific effects – by $\Phi(\tau_i)$.

These interpretations assume that the regression coefficients are indeed consistent estimates of the underlying true model. Simply estimating (1) using OLS when $(3')$ is the true model is, however, unlikely to achieve this because the error term in $(3')$, $\mu_i \equiv \beta\left[\tilde{\sigma}_i - \tilde{E}_{0,i}\right] + \delta\left[\tilde{E}_{1,i}^f - \tilde{E}_{0,i}^f\right]_{1,i}^f + \varepsilon_i$, is likely to be correlated with q_i for several reasons.

First, as already mentioned, there could be a systematic relationship between ε_i and q_i because the ECB's bond purchases were not random. In particular, if the ECB was purposefully targeting bonds with "abnormally high" yields – and we have already shown evidence consistent with this – it is conceivable that yields of these bonds would have come down faster during the period studied even if the ECB had not engaged in any purchases. In that case, the slope coefficients in a cross-sectional regression would conflate two effects: any ECB purchase effect, plus the downward "correction" of the yield of ECB-picked bonds in the post-announcement period.

Second, ε_i and q_i could be correlated because of non-SMP related news during the intervention period that one would expect to impact bond yields, in particular the EFSF announcement of May 9, or news on Greek politics and the €110 bn Greek rescue programme. The presence of such news does not create a problem so long as it affects all bonds equally. However, some news may have had a differential impact across bonds, in a way that might be correlated with the ECB purchases in those bonds. For example, we know that the ECB preferred to buy shorter and medium maturities. At the same time, it is possible that the initial SMP and EFSF announcements disproportionately impacted these bonds. We

also know that the ECB preferred Greek-law bonds, which could similarly have been disproportionately impacted by the programme announcements.[29] If these correlations were present, they could bias up the slope coefficient in an OLS regression.

Third, estimating equation (1) using OLS when the true model is $(3')$ may give rise to inconsistent estimates due to the likely correlation between $\tilde{\sigma}_i$, the *perceived* deviations of actual intervention from the mean, and q_i, the *actual* intervention. $\tilde{\sigma}_i$ is a noisy signal of q_i, so unless markets were entirely in the dark on the size of interventions in specific bonds, our inability to control for perceptions about individual bond purchases will give rise to an upward bias in the estimate of the direct purchase effect θ. The closer perceptions $\tilde{\sigma}_i$ are to actual interventions q_i, the closer we are, in effect, to model (3) (the LSAP case), in which the slope coefficient of q_i is an estimator of the *combined* announcement and purchase effects $\beta + \theta$.

Fourth, a specification problem could arise through the expectations terms in the error term μ_i. In particular, if markets form expectations about future interventions, $\tilde{E}^f_{1,i}$ based on perceptions of actual purchases during the intervention period, this would also bias upward the estimated purchase coefficient θ.

In general, we are less concerned about the third and fourth source of endogeneity – i.e. the correlation between actual, perceived, and future expected purchases of bond *i*. The reason is that in the presence of these correlations alone (i.e. abstracting from the first two problems discussed above) the coefficient estimate of θ would still unambiguously reflect the effect of actual or anticipated ECB purchases. We would just not be in position to disentangle announcement, expectations, and direct purchase effects.

We address the various sources of endogeneity in two ways:

- To deal with the first two, – ECB selection of underpriced bonds and correlated news – we include additional controls in the regression. First, we control for pre-SMP bond yields, which should account for the fact that the yield of "underpriced" bonds chosen by the ECB may have declined even without ECB purchases in those bonds. Second, to deal with news shocks, we include controls such legal risk (domestic law dummy), bond maturity, and, most importantly, a time-varying proxy for the perceived risk of Greek default (and Eurozone exit). Specifically, we use Greek CDS premia from JP Morgan and match each bond with the closest maturity for which CDS pricing data is available, namely from 1 year to 10 years, as well as for 30 years. CDS premia are well-suited to account for the effect of news shocks on Greek default and LGD risk at

[29]If investors believed, at the time, that Greece had a deep solvency problem that would not necessarily be resolved by the SMP and the EU-IMF programme, the SMP might have been viewed as "kicking the can down the road". This would have implied a smaller drop in yields of long bonds than short bonds.

different maturities, both because they are priced off relatively liquid instruments and because we know that the ECB did not intervene in the CDS market, as mentioned above.

- To address all possible sources of endogeneity simultaneously, we also run a two-stage least squares regressions using bond characteristics, measured on the day prior to the start of the programme (here: May 7), as instruments.[30] Specifically, we use bond size, coupon size, and the dummy for benchmark bonds. These variables are good predictors of ECB purchases, as shown in section 3, but do not belong in the main regression. Standard IV tests indicate that the instruments are valid but weak.[31]

An alternative is to test the ECB intervention effect using a difference-in-difference type approach with daily data, thus distinguishing between the pre- and post-announcement period (similar to Krishnamurthy and Vissing-Jorgensen(2011) and Duygan-Bump et al.(2013)). This amounts to a panel regression of yield *levels* with bond fixed effects and time fixed effects and a "treatment variable" consisting of the interaction between the post-announcement period dummy and a variable reflecting ECB intervention in each bond. The effects of ECB intervention are picked up by this interaction term.[32] Compared to the cross-sectional regression, the advantage of this approach is that it allows us to estimate bond fixed effects, which absorb all bond-specific characteristics that we may have failed to control for in the cross-sectional regression.

The disadvantage of the difference-in-difference regression is that the modelling of the "treatment effect" implicitly assumes that for each bond, the same ECB "treatment" applies on every day after the SMP announcement, which is not true of course. To address this final problem one can estimate a version of the difference-in-difference specification in which all daily observations before and after the announcement are averaged into just one pre-announcement period and one post-announcement period (following Bertrand, Duflo, and Mullainathan 2004). The ECB treatment dummy will then be measured without error, since it simply captures *any* purchases after May 9th. A further advantage of the two-period panel is that it accounts for serial correlation in a very conservative way.[33]

[30] This follows the approach of D'Amico and King (2013). Following their strategy, we also estimated a "fitting error" for each bond to proxy whether it was under or overpriced. Specifically, we use the residuals from fitting a Svensson-type yield curve to the cross-section of Greek bond yields on May 7. This variable, however, turned out to be insignificant in both the first and second stage regression and could therefore not be used as IV for ECB purchases.

[31] In our baseline specifications, the Sargan test of overidentifying restrictions indicates valid instruments (the null cannot be rejected), while the LM test for underidentification indicates weak instruments (the null can be rejected in most specifications, but often only at the 5% or 10% level).

[32] The ECB level intervention in each bond is a bond-specific constant and hence absorbed by the bond fixed effect.

[33] In the daily panel, we cannot rule out that serial correlation may result in downward-biased standard errors, even though we already cluster standard errors on the bond level in all specifications.

4.4. Cross-sectional estimation

Table 4 shows our main cross-sectional results, in line with model (3´) and for the 37 Greek sovereign bonds with reliable yield data.[34] The dependent variable is the change in yields (drop) after the start of central bank interventions on May 7, just prior to the inception of the SMP. The main time window of interest includes the first 8 weeks of SMP interventions, from May 7 until July 5 2010, after which the ECB purchases of Greek bonds come to a nearly complete halt (see above). The main explanatory variable is the amount of ECB purchases in % of total amounts outstanding in each bond series. Controls include the remaining bond maturity as included in equation (3´) (measured as of May 7 2010),[35] the change in CDS premia as a proxy for default and LGD risk, and a dummy for Greek-law bonds to account for legal risk. Pre-SMP yields are measured as yield increase 4 weeks prior to the SMP (from April 12 to May 7), but the results are very similar if we control for yield levels instead of yield increases, as discussed in the robustness section.

Columns (1) to (3) show the results for our main 8-week time window. The coefficient of "ECB purchases" is highly significant and has a size of -0.145 in our most conservative specification (column (2), which controls for pre-SMP yields). A 10 percentage point increase in ECB purchases in a series is thus associated with a yield drop of 1.45 percentage points in that bond, or -145 basis points. Put differently, the estimated coefficient suggests that an additional €1 bn in ECB purchases results in a drop in yields of 204 basis points in that individual bond.[36] To approximate the total effect of ECB purchases, we can also conduct simple back-of-the-envelope calculations. Specifically, we can assume that the total purchases in the first 8 weeks (estimated at €41 bn, see above) had been spread evenly across all 37 Greek bonds that were trading on secondary markets at the time. This would translate into €1.108 bn per bond and a total yield impact of 226 basis points (1.108 *204), after controlling for term structure effects and changes in default (and LGD) risk due to the SMP and EFSF announcements and other news.

In Column (3), we instrument ECB purchases with bond characteristics prior to the start of interventions. The coefficient remains significant and becomes slightly larger in absolute size. We also find results to hold in a shorter time windows, in particular 1 day, 1 week, and 4 weeks after SMP start (see columns (4) to (12)). As could be expected, the estimated coefficient for ECB purchases becomes smaller in size the shorter the time window chosen, which likely reflects the fact that our proxy for interventions measures total purchases and

[34] Six bonds in our sample stop trading in late May and June 2010, after the first weeks of ECB intervention. The sample therefore drops from 37 to 31 bonds in regressions with longer time spans.
[35] We also included maturity squared, in line with model (3), but this variable never turned out as significant.
[36] In this sample of 31 bonds, the purchase amount of €1 bn corresponds to a holding share of 14%. This comes by comparing the average bond size in this sample (€7.11 bn) with the average amount of ECB purchases in this sample (€1.37 bn). The quantitative impact of €1 bn purchases can therefore be computed by multiplying the average holding share with our estimated coefficient (14*-0.14523 = -2.04 percentage points).

therefore only imperfectly accounts for amounts purchased in the first few days or weeks of the programme.

Table 5 shows results from various robustness checks.

- First, we replace our proxy for bond underpricing, the yield increase in the 4 weeks pre-SMP, with two alternative measures of pre-SMP yield levels. Column (1) includes the yield of May 7 a control (the last trading day prior to the announcement of the SMP), while column (2) includes average yields in the 4 weeks from April 12 until May 7. The results are similar to those in our baseline specification, although the ECB purchase variable has a somewhat smaller coefficient.
- In a second step, we account for the possibility of substitution effects and capture the scope of purchases of close substitute bonds, meaning those with similar maturities. For this purpose, we follow D'Amico and King (2013) and compute a bond-specific measure of the share of ECB purchases in bonds of the same maturity segment, defined as a two-year window around the maturity of each bond (one year before until one year after). Column (3) shows that this variable is insignificant, consistent with highly imperfect substitution across bonds of the same sector. This said, a high degree of collinearity with the variable on own purchases and also the maturity measure makes this result difficult to interpret. The measure on close substitute purchases becomes weakly significant if we drop the maturity control (and highly significant if we drop both maturity and own purchases).
- Columns (4) and (5) of Table 5 show that the results are nearly identical if we use yield spreads above German Bunds instead of plain yields, which gives further reassurance that our results are not driven by the signalling channel of central bank purchases. Indeed, any effect of the SMP on expected future interest rates and ECB monetary policy should shape the German yield curve in a similar way to the Greek one.
- We also show results in a weighted least squares framework, using bond size (amount outstanding in € bn) as weighting parameter. The idea behind is that measurement errors in the yield data may be smaller for larger bonds, which are relatively more liquid. Columns (6) and (7) show that the results are similar in our baseline specifications. But the ECB purchase measure turns insignificant in the twostage regression of column (8), which also controls for pre-SMP yields (column (7)). Once we drop the pre-SMP yield measure the instrumented ECB purchase variable becomes significant again (with a coefficient of -0.21).

4.6. Differences-in-differences estimation

Table 6 shows results from our difference-in-difference type estimations, using a daily panel for all 37 bonds for which yield data was available on a regular basis.[37] The estimations can be thought of as an extension of the previous cross-sectional regression, using yield levels as

[37] There is no yield data for 6 bonds in late June and early July of 2010. The panel is therefore unbalanced.

dependent variable and with θ estimated by the interaction term of ECB interventions and the post-SMP time dummy. To account for bond characteristics and time trends, all regressions include bond fixed effects and day fixed effects. Standard errors are clustered at the bond level, albeit the results are similar without clustering. As before, our main time window spans the 8 weeks after the start of the SMP in which most bond purchases occurred (from May 10 until July 5) and we now add a pre-treatment period for the 8 weeks pre-SMP (from March 15 until May 9). Again we also show results for shorter time windows, namely 4 weeks and 1 week before and after May 9.

In all specifications, the "treatment" variable (the interaction of ECB interventions and post-SMP dummy) is highly significant and negative, consistent with the hypothesis that central bank secondary market purchases lowered yields in those bonds that were intervened in. Our most conservative specification is column (2) of Table 6, as it includes a lagged control of pre-SMP yield increases to account for the fact that the ECB might have targeted bonds with "abnormally high" yields. The resulting coefficient is -1.74, suggesting that, on average, yields of targeted bonds dropped by 1.74 percentage points more compared to the counterfactual (bonds with no purchases). The results are nearly identical if we define the target dummy with a minimum intervention amount, e.g. only including bonds with at least 5% of ECB holdings. The resulting intervention coefficient drops to -1.57 but remains highly significant.

The results are also very similar when using a continuous measure for the extent of interventions (purchases as a percentage of amount outstanding, see columns (5) through (8)). Column (6) shows that the coefficient of the interaction term between the extent of purchases and the post-SMP dummy is -0.10. This suggests that a 10 percentage point increase in purchases reduces yields by 100 basis points in those bonds, on average.[38] Put differently, the estimated coefficient suggests that an additional €1 bn in ECB purchases results in a drop in yields of 160 basis points in that individual bond.[39] Like in the cross-sectional exercise, this bond-level figure can be used to approximate the total impact of ECB purchases between May 9 and July 5, by multiplying -160 with €1.108 bn(i.e. presuming the ECB had spread its total purchases of €41 bn equally across all 37 traded bonds). The resulting back-of-the-envelope estimate of total purchases is -177 basis points.

The "treatment" coefficients are somewhat higher for the shorter time windows chosen in columns (3) and (7) (1 week before and after SMP start) and in columns (4) and (8) (4 weeks before and after). This is particularly true for the regressions with the plain ECB intervention dummy. Accordingly, we can interpret the estimated "treatment" coefficient of -2.44 in

[38] The average share of ECB holdings across bonds is 14.84% in this sample. Multiplying with the estimated coefficient results in a total estimated yield impact of -1.51, which is roughly consistent with the result in column (3).

[39] In this sample, the purchase amount of €1 bn corresponds to a holding share of 16.1% in the average bond. The quantitative impact of €1 bn purchases in individual series can therefore be computed as 16.1*-0.102 = -1.6 percentage points.

column (4) as a conservative upper bound for the effect of ECB purchases on average yields in the Greek sovereign bond market of mid-2010.

Table 7 shows various robustness checks using the cleaner specification with the ECB intervention dummy as baseline. As in Table 5, we find no significant effect for ECB purchases of close substitute bonds in the same maturity segment (column (1)). We also find that the main results continue to hold when using yield spreads above Bunds instead of plain yields (column (2)), when weighting the regression using bond size as weighting parameter (column (3)) and when controlling for yield levels pre-SMP instead of yield increases (result not shown, but available upon request).

More importantly, we find that the results continue to hold in a two-period panel with average yields in the pre-treatment and post-treatment period (before and after May 9). The main coefficient of interest - the interaction of the post-SMP dummy and the ECB intervention dummy - is again highly significant and the magnitude of the effects is about the same as in the daily panel. This is true for the main time window of 8 weeks (column (4)), but also with a shorter time window of 1 week (column (5)) and 4 weeks (column (6)). These results give us confidence that measurement errors in the extent of ECB intervention did not seriously bias the previous set of results. It also confirms that the results hold when accounting for serial correlation in a very conservative way.

5. Conclusion

This paper undertakes a granular analysis of ECB sovereign bond buying in the context of the Greek debt crisis. We show that the ECB applied simple “rules of thumb” when choosing which sovereign Greek bonds to purchase. It left the majority of bonds untouched and focused purchases on large benchmark bonds. It also targeted bonds with relatively high yields. These findings may be relevant for European policymakers, as well as for investors currently holding bonds of Eurozone peripheral countries.

The results indicate very large effects of ECB interventions in times of turmoil. All available evidence suggests that the purchases had a large impact on the price of individual Greek bonds, even after controlling for changes in Greek default risk, LGD risk, and bond fixed effects. These findings are difficult to reconcile with standard term structure models, but they are consistent with Vayanos and Vila (2009), Greenwood and Vayanos (forthcoming) and other models with limited arbitrage and illiquid, segmented bond markets.

The total effect was largest at the short end of the yield curve (bonds with maturities of up to 5 years). Indeed, the term structure of Greek bonds changes drastically within a matter of days after the launch of the SMP – at a speed and scale that is unprecedented in advanced economies thus far. The graphs alone illustrate how important the official interventions have been for short-term yields dynamics. At the same time, it is clear that the effects quickly

dissipated after SMP intervention stopped and confidence in Greek debt sustainability eroded further in late 2010 and 2011. These facts may help to rationalise the design of the SMP's successor programme, the OMT, which targets the maturity range at which the SMP appeared to be most effective and represents an unlimited commitment, but is also conditional on satisfactory fiscal and structural adjustment.

Figure 1: Distribution of Greek bond holdings

The figure shows the distribution of holdings of Greek sovereign bonds (issued by the Hellenic Republic) just prior to the Greek debt exchange of Febr./March 2012 by type of holder. The amount held by the ECB corresponds to purchasing amounts via the SMP.

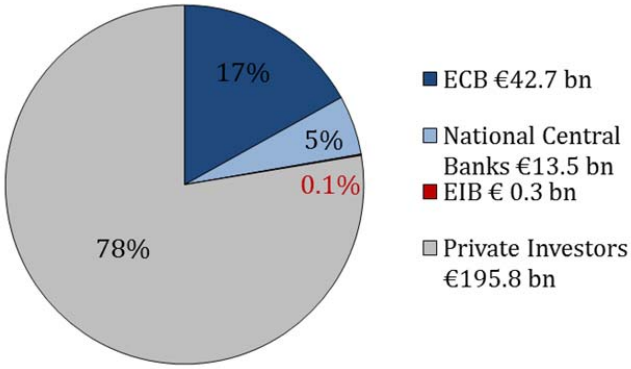


Figure 2: ECB holdings of the 20 largest Greek bonds

This figure illustrates the large variation in ECB purchases across Greek sovereign bonds. To do so, the figure ranks the 20 largest Greek sovereign bonds by their total size (grey bars) and also shows the amount and share of each bond purchased by the ECB (blue bars and red line, respectively). The x-axis is ordered by bond size (in € bn), while the identifiers represent the maturity of each of the 20 largest Greek bonds. The identifier is not unique because more than one bond matures in 2012, 2014, and 2015, respectively.

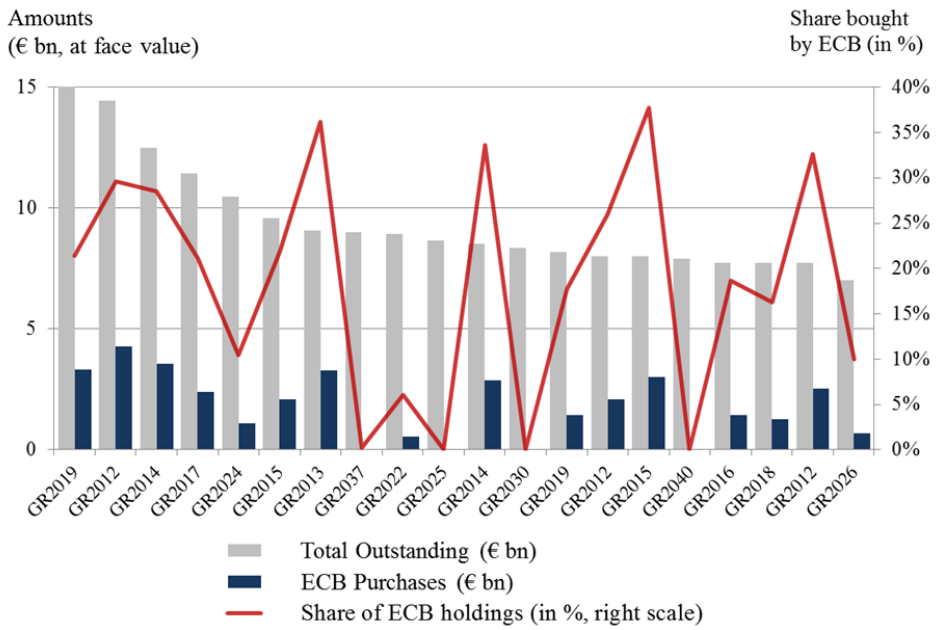


Figure 3: Maturity distribution of ECB holdings

The figure shows the maturity distribution of ECB holdings of Greek government bonds and compares it to the maturity structure of all Greek government bonds, as of February 2012.

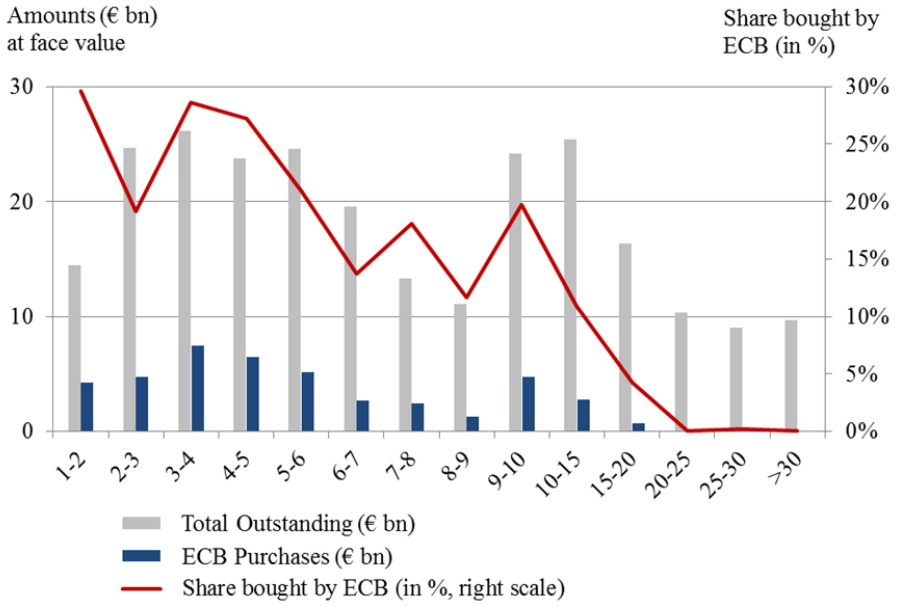


Figure 4: Bond yields (pre-SMP) and ECB purchases

The figure shows the relationship between ECB purchase (in % of face value of each bond) and bond yields in the month prior to the start of the SMP (average yield between April 12 and May 7). There is a strong positive relationship between the yield of a bond and the amount of subsequent purchases.

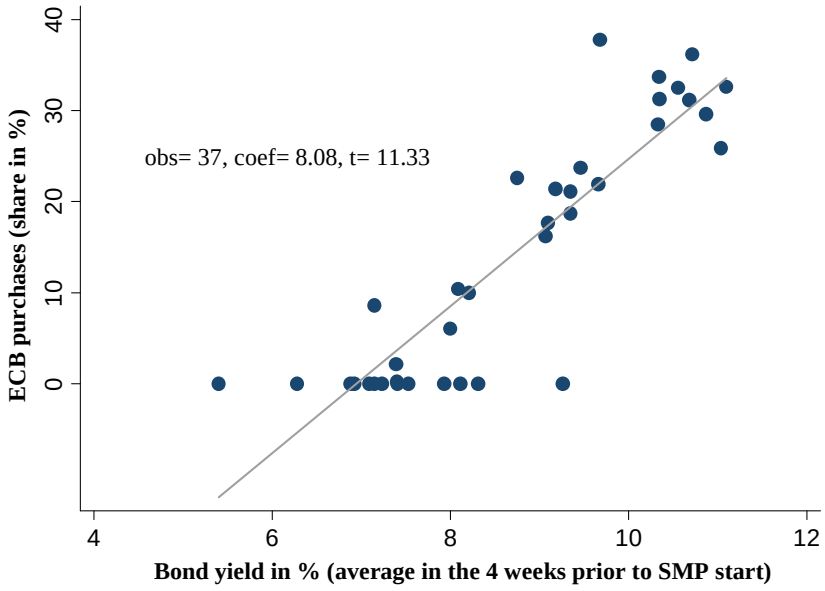


Figure 5: Average bond yields and total ECB purchases

The figure shows the development of bond yields, averaged across all Greek government bonds for which data was available and weighted by bond size (outstanding volume in €). Source: Bloomberg, own calculations.

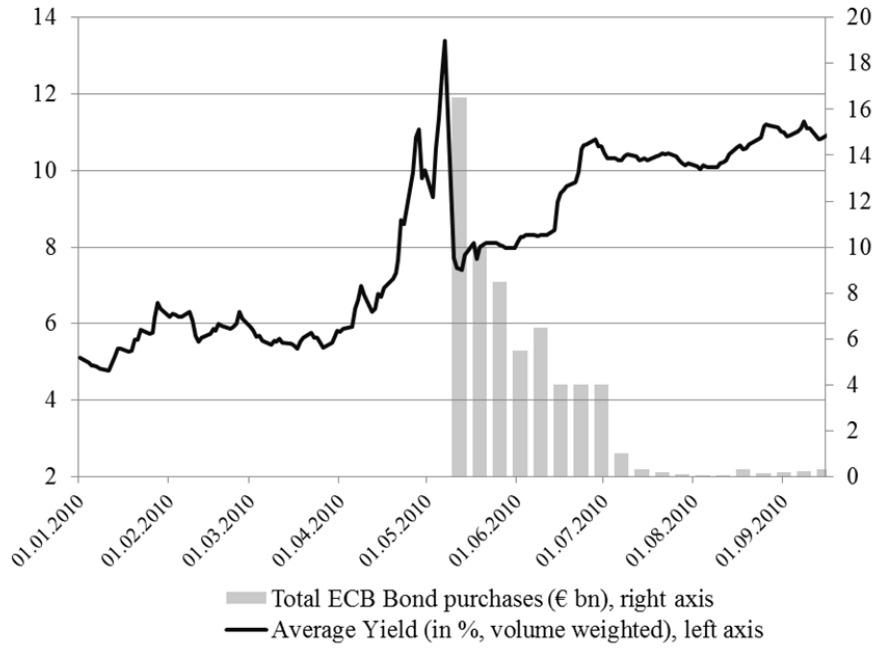
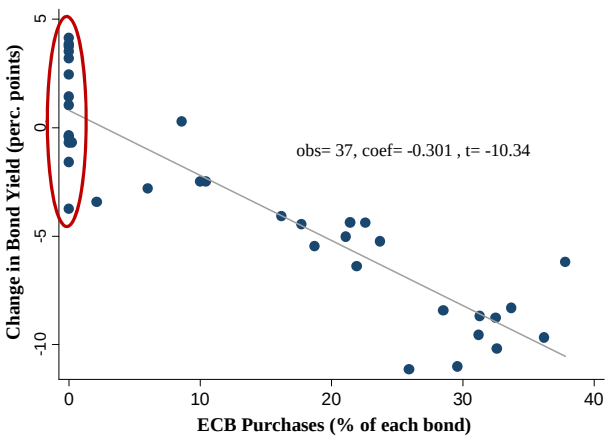


Figure 6: ECB purchases and yield drop in the cross section of bonds

This figure shows the yield change (drop) between May 7 (just before the start of the SMP) and subsequent dates: 1 week later in Panel A and 8 weeks later in Panel B. Bonds not targeted by the ECB (zero purchases) see an increase in bond yields, on average (red circle).

Panel A: Drop in yields between May 7 and May 17 (1 week later)



Panel B: Drop in yields between May 7 and July 5 (8 weeks later)

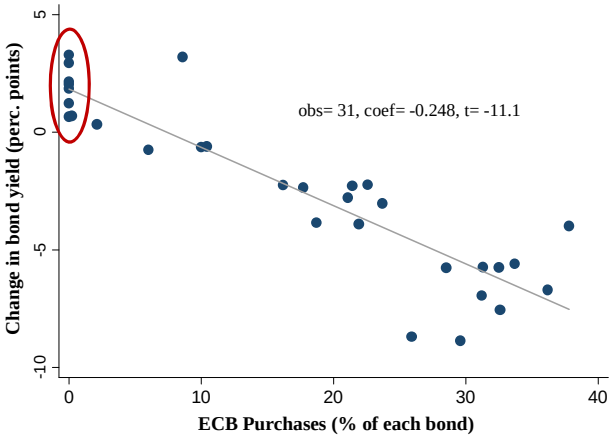
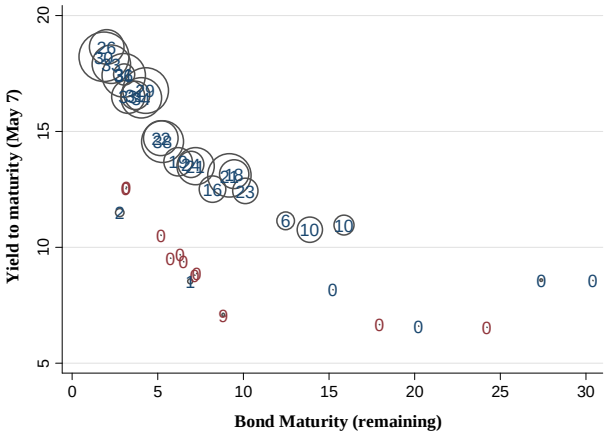


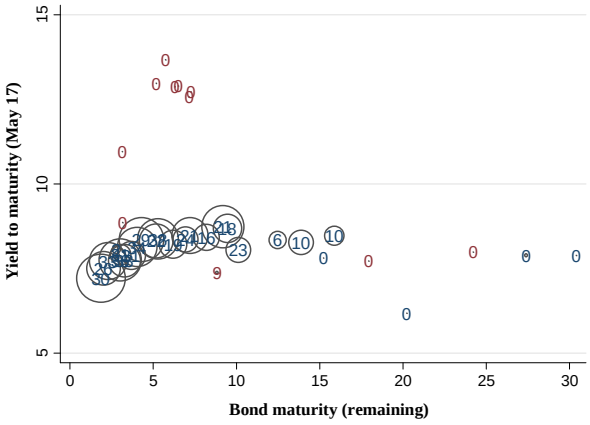
Figure 7: The Greek bond yield curve – before and after May 9 2010

This figure plots the Greek yield curve pre-SMP (on May 7) as well as 1 and 8 weeks after its start (May 17 and July 5). The sample includes all Greek sovereign bonds for which yield data was available. The size of the circles reflects the volume bought by the ECB, while the figures show ECB bond holdings as a percentage of total amount outstanding. Bonds marked in red are foreign-law bonds.

Panel A: Yield curve on May 7 (pre-SMP)



Panel B: Yield curve on May 17 (1 week after SMP start)



Panel C: Yield curve on July 5 (8 weeks after SMP start)

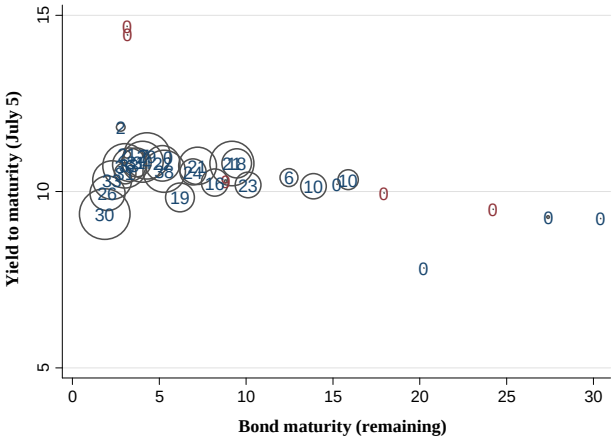


Figure 8: Greek CDS yield curve

This figure shows CDS premia on May 7, May 17, and July 5, respectively. The x-axis shows maturities, ranging from 1 year to 30 years. The data on CDS premia is from JP Morgan.

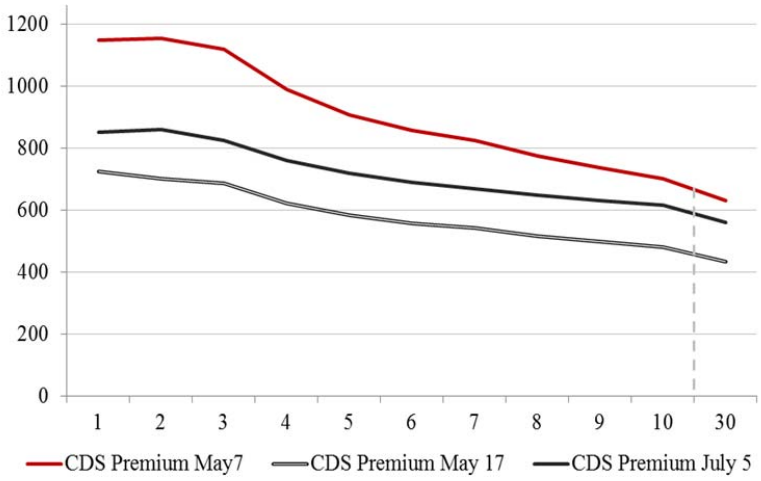
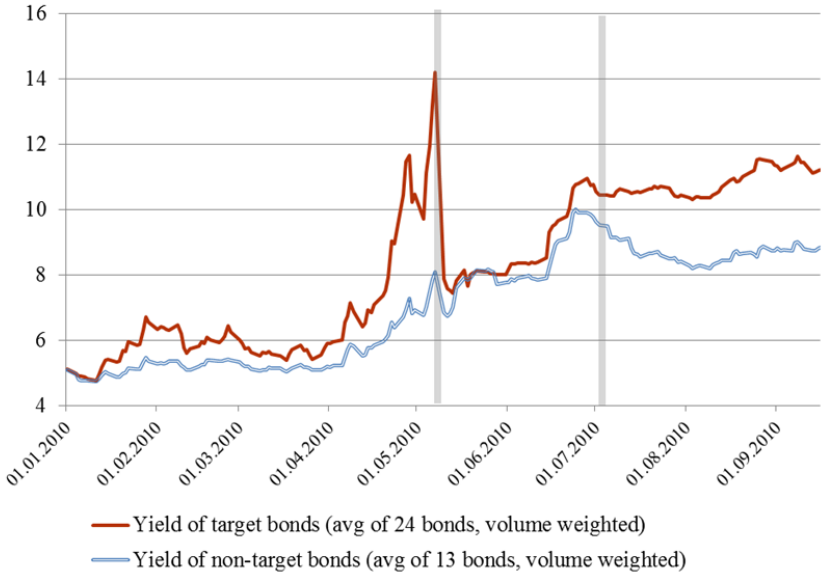


Figure 9: Average yields of targeted vs. non-targeted Greek bonds

Panel A: Average yields (levels)

The red line shows average yields for the subsample of 24 bonds that were targeted by the ECB, while the blue line shows average yields for the 13 non-targeted bonds, both weighted by bond size (par amount in € bn). Targeted bonds are defined as those with some ECB holdings (>0), although the figure looks very similar when target bonds are defined as those with ECB holdings of at least 5% of face value. The grey bars show the start and end of large-scale SMP bond purchases (from May 10 to early July 2010). The ECB purchases are largest during the first three weeks (May) and then decrease steadily until early July.



Panel B: Residual average yields

This figure plots the residuals of a regression of yields on bond fixed effects. Residual yields of the 24 targeted bonds are shown in red, those of the 13 not-targeted bonds in blue (averages weighted by bond size).

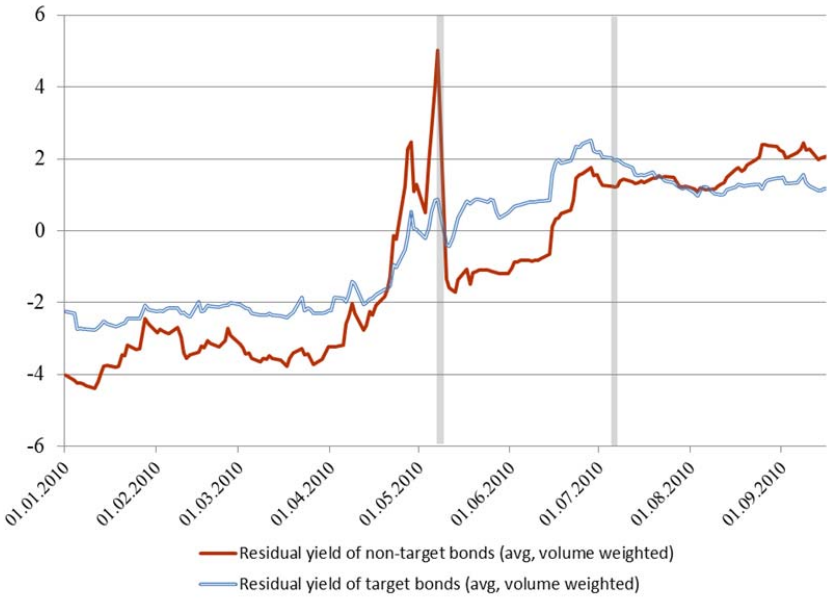


Figure 10: Comparing yields of "twin bonds" with and without purchases

This figure compares the yield development of similar bonds ("twins") with different degrees of ECB interventions. The grey bars show the start and end of large-scale SMP bond purchases. In both cases, the yield premium of the targeted bond is considerably reduced during the period of interventions.

Panel A: 2024 vs. 2025 bond

This panel compares a targeted 2024 bond with a 4.7% coupon (red line, 10.4% purchased by ECB) and a non-targeted 2025 bond with a floating interest rate set at 2.9% above the Eurozone HICP inflation rate (blue line, 0% purchased).

Panel B: 2020 vs 2022 bond

This panel compares a targeted 2020 bond with a 6.2% coupon (red line, 22% purchased by ECB) and a less-targeted 2022 bond with a 5.9% coupon (blue line, 6% purchased).

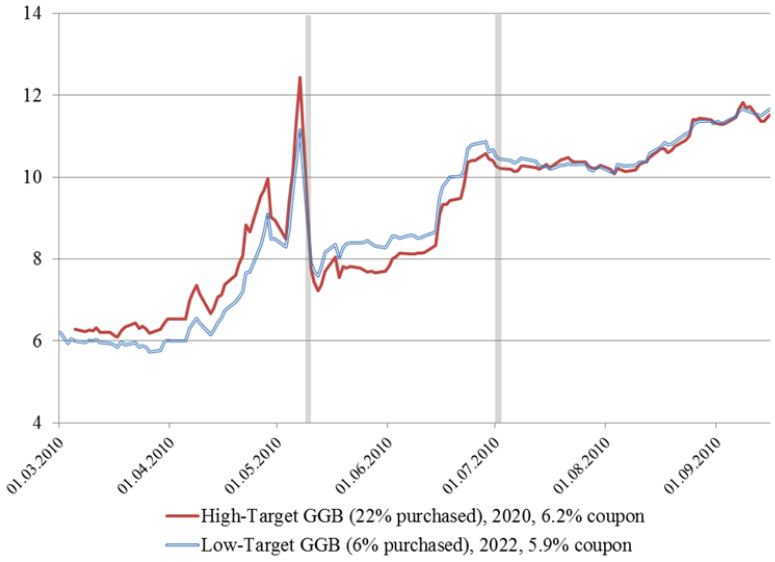


Table 1: Summary statistics of Greek government bonds

This table compares sample averages for Greek bonds bought by the ECB to the full sample of bonds (all outstanding securities). All figures are Euro-weighted means.

	Average of ECB purchases	Average of all outstanding bonds
Remaining maturity /1	5.4 years	9.1 years
Coupon	5.0%	4.5%
Time since issued /2	3.8 years	4.0 years
% Greek-law bonds	99.9%	92.6%
% Benchmark bonds	94.7%	74.5%
% Priced on Bloomberg	100.0%	93.5%
Yield average (pre-SMP) /3	10.0%	9.0%

/1 Remaining maturity as of May 7, 2010 (at start of SMP)
/2 Age of the bond as of May 7, 2010 (at start of SMP)
/3 Four week average between April 12 and May 7, for all bonds with yield data

Table 2: Summary statistics of bond measures used in the regression analysis

Variable	Unit	Data source	Obs	Mean	Std. Dev.	Min	Max
ECB purchases (in € bn)	billion Euro	Own calculations based on Bloomberg / Greek Min. Fin.	81	0.53	1.03	0	4.27
ECB purchases (share of bond, in %)	in perc. points	Own calculations based on Bloomberg / Greek Min. Fin.	81	6.80	11.58	0	37.80
ECB purchases of close substitutes (similair maturity, in %)	in perc. points	Own calculations based on Bloomberg / Greek Min. Fin.	81	17.25	8.33	0	28.69
Bond size (Amount outstanding, € bn)	billion Euro	Bloomberg / Greek Min. Fin.	81	3.12	4.07	0.02	15.50
Remaining maturity (in years)	years	Bloomberg / Greek Min. Fin.	81	8.46	7.29	1.86	47.24
Coupon	in perc. points	Bloomberg	80	3.98	1.64	0	7.50
Greek law bond (dummy)	1 if yes	Zettelmeyer et al. (2013)	81	0.65	0.48	0	1
Benchmark bond (dummy)	1 if yes	Bloomberg, own calculations	81	0.30	0.46	0	1
Yield change pre-SMP, in % (increase from April 12 to May 7)	in perc. points	Bloomberg, own calculations	38	5.60	3.42	-0.36	11.68

Table 3: Determinants of ECB purchases

This table shows results from an OLS regression in the cross-section of Greek bonds. The dependent variable is the share of ECB purchases in each series (in % of total face value). Columns (1) to (6) are based on the full sample of 81 Greek government bonds. Columns (7) to (9) use a sample of bonds for which yield data is available from Bloomberg. ***/**/* indicates significance at a 1%, 5%, and 10% level, respectively. Robust standard errors are in parentheses.

	Full Sample						Subsample for which yield data is available		
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
	coef/se	coef/se	coef/se	coef/se	coef/se	coef/se	coef/se	coef/se	coef/se
Bond size (amount	1.93***					1.21***		0.58*	0.32
outstanding, € bn)	(0.25)					(0.34)		(0.31)	(0.33)
Remaining maturity		-0.41***				-0.46**			-0.20
(years, in May 2010)		(0.14)				(0.20)			(0.27)
Coupon size			2.92***			1.42**			2.74***
(in %)			(0.60)			(0.62)			(0.94)
Greek law bond				9.79***		-0.57			
(Dummy)				(1.83)		(1.51)			
Benchmark bond					17.65***	7.81**			6.53*
(Dummy)					(2.64)	(3.92)			(3.41)
Yield pre-SMP, in %							3.07***	2.76***	2.10***
(4-week average)							(0.31)	(0.39)	(0.68)
Constant	0.80	10.27***	-4.76**	0.40	1.57**	-0.69	-4.38**	-6.00**	-15.62***
	(0.68)	(2.13)	(1.86)	(0.31)	(0.77)	(2.58)	(2.08)	(2.61)	(6.01)
Observations	81	81	80	81	81	80	37	37	37
R^2 (adjusted)	0.451	0.055	0.160	0.153	0.484	0.627	0.677	0.696	0.775

Table 4: Cross-section on the effects of bond purchases on yields

This table shows OLS regressions results in the cross-section of Greek bonds for which yield data is available. The dependent variable is the change (drop) in bond yields between Friday May 7 (before SMP start) and subsequent dates, in percentage points. The main explanatory variable captures the scope of ECB intervention, measured as the share of ECB purchases in each series (in % of total face value). A negative coefficient indicates that this variable is associated with a lower yield across bonds. Columns (3), (6), (9) and (12) show results from a two-stage least squares regression using "Bechnmark bond", "Bond size (amount outstanding)" and "Coupon" as instruments for ECB bond buying shares. The variable "Yield increase pre-SMP" captures the yield increase of each bond in the 4 weeks before the start of the SMP (from April 12 to May 7), measured in percentage points. The variable "Change in CDS premia" captures the change (drop) in CDS premia after the start of SMP, also in percentage points. Robust standard errors are in parentheses. ***/**/* indicates significance at a 1%, 5%, and 10% level, respectively.

	Dependent Variable: Yield change after May 7…											
	8 week (May 7 vs July 5)			**1 day** (May 7 vs May 10)			**1 week** (May 7 vs May 17)			**4 week** (May 7 vs June 7)		
	OLS	**OLS**	**2SLS**	**OLS**	**OLS**	**2SLS**	**OLS**	**OLS**	**2SLS**	**OLS**	**OLS**	**2SLS**
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
ECB Purchases	-0.17***	-0.15***	-0.20***	-0.13***	-0.10***	-0.08***	-0.17***	-0.13***	-0.10*	-0.17***	-0.11***	-0.15***
(share of bond, in %)	(0.03)	(0.03)	(0.03)	(0.02)	(0.02)	(0.03)	(0.03)	(0.05)	(0.06)	(0.03)	(0.03)	(0.04)
Remaining Maturity	-0.09**	-0.12***	-0.14***	0.01	-0.02	-0.01	-0.12**	-0.16***	-0.15***	-0.02	-0.07**	-0.08***
(in years)	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.05)	(0.06)	(0.06)	(0.03)	(0.03)	(0.03)
Greek Law Bond	-2.78***	-1.81***	-1.73***	-2.62***	-1.60***	-1.69***	-3.62***	-2.15***	-2.24***	-3.48***	-1.80**	-1.77***
(Dummy)	(0.60)	(0.69)	(0.30)	(0.43)	(0.39)	(0.42)	(0.76)	(0.72)	(0.66)	(0.66)	(0.74)	(0.51)
Change in CDS Premia	-3.08***	-1.65**	-2.30***	-2.09***	-0.91***	-0.66	-2.44***	-1.18**	-0.99	-1.72***	-0.31	-0.63*
(in %, by maturity)	(0.56)	(0.74)	(0.71)	(0.41)	(0.33)	(0.46)	(0.43)	(0.56)	(0.61)	(0.34)	(0.27)	(0.35)
Yield pre-SMP (increase		-0.39**	-0.19		-0.39***	-0.49***		-0.57*	-0.67*		-0.64***	-0.49**
from April 12 to May 7, in %)		(0.17)	(0.13)		(0.13)	(0.14)		(0.34)	(0.37)		(0.18)	(0.19)
Constant	4.82***	5.89***	5.80***	5.89***	3.60***	3.02***	10.11***	8.38***	8.03***	4.83***	4.56***	4.98***
	(0.57)	(0.74)	(0.51)	(1.27)	(0.89)	(1.14)	(1.55)	(1.28)	(1.27)	(0.99)	(0.69)	(0.69)
Observations	31	31	31	37	37	37	37	37	37	32	31	31
R^2 (adjusted)	0.947	0.957	0.948	0.957	0.966	0.964	0.933	0.945	0.944	0.945	0.971	0.966

Table 5: Robustness - cross-section on the effects of bond purchases

This table expands our main cross-sectional analysis of Table 4. Columns (1) and (2) control for yield levels, instead of the yield increase from April 12 to May 7 as in our main specification Yield levels are measured in percentage points as of May 7 (just prior to the SMP inception) in column (1) and as yield averages from April 12 to May 7 (in the 4 weeks pre-SMP) in column (2). Column (3) accounts for ECB purchases of close substitute bonds, meaning bonds within 2 years maturity of the bond's own maturity (1 year more or 1 year less), expressed as share of total bonds outstanding in the respective maturity bucket, in percentage points. Columns (4) and (5) use yield spreads above German Bunds as dependent variable (in percentage points), instead of absolute yields, as in all other specifications. Columns (6), (7) and (8) show results for weighted least square regressions using total bond amount outstanding (in € bn) as weighting parameter. Columns (5) and (8) show results from a two-stage least squares regression using "Benchmark Bond", "Bond Size (amount outstanding)" and "Coupon" as instruments for ECB bond buying shares. The variable "Change in CDS Premia" captures the change (drop) in CDS premia after the start of SMP, also in percentage points. Robust standard errors are in parentheses. ***/**/* indicates significance at a 1%, 5%, and 10% level, respectively.

	Controlling for yield levels		**With close substitutes**	**Yield spreads (above Bunds)**		**Weighted least squares**		
	8 week (May 7 vs July 5)		8 week (May 7 vs	8 week (May 7 vs July 5)		8 week (May 7 vs July 5)		
	OLS (1)	**OLS** (2)	**OLS** (3)	**OLS** (4)	**2SLS** (5)	**Weighted LS** (6)	**Weighted LS** (7)	**Weighted 2SLS** (8)
ECB purchases	-0.11***	-0.11***	-0.18***	-0.15***	-0.20***	-0.15***	-0.05**	-0.07
(share of bond, in %)	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.05)	(0.02)	(0.11)
Remaining maturity	-0.08**	-0.12***	0.07	-0.13***	-0.14***	-0.05	-0.14***	-0.14***
(in years)	(0.04)	(0.04)	(0.07)	(0.04)	(0.03)	(0.05)	(0.04)	(0.04)
Greek law bond	-2.80***	-1.82***	-2.51***	-1.84**	-1.76***	-3.26***	-1.80	-1.82*
(Dummy)	(0.49)	(0.56)	(0.76)	(0.72)	(0.33)	(1.06)	(1.13)	(1.02)
Change in CDS premia	-2.28***	-1.47**		-1.86**	-2.53***	-3.33***	-0.35	-0.67
(in %, by maturity)	(0.57)	(0.60)		(0.79)	(0.75)	(0.60)	(0.61)	(1.71)
Yield pre-SMP (increase from April				-0.38**	-0.18		-0.98***	-0.86
12 to May 7, in %)				(0.18)	(0.14)		(0.18)	(0.65)
Yield level pre-SMP	-0.79**							
(on May 7)	(0.37)							
Yield level pre-SMP (4 week average		-0.53***						
from April 12 to May 7)		(0.17)						
ECB purchases of close substitutes			-0.00					
(maturity within 2 years of own, in %)			(0.04)					
Constant	10.51***	9.44***	2.23	6.21***	6.12***	4.56***	8.01***	7.71***
	(2.62)	(1.57)	(1.39)	(0.78)	(0.54)	(0.80)	(1.27)	(2.13)
Observations	31	31	31	31	31	31	31	31
R^2 (adjusted)	0.953	0.958	0.843	0.946	0.936	0.922	0.962	0.961

Table 6: Daily panel on the effects of bond purchases

This table reports differences-in-differences-type results using a panel of daily bond yields and including day fixed effects and bond fixed effects. The main explanatory variable is a measure for ECB interventions interacted with a "Post-SMP indicator" which is 1 after the start of the SMP on May 9. ECB intervention is captured either via a dummy on whether the bond was targeted by the SMP (columns (1) to (4)) or as a continuous measure on the share of ECB purchases in each series (columns (5) to (8)). The main specification (columns (1), (2), (5), and (6)) includes the eight weeks before and eight weeks after the start of the SMP on May 9. Columns (3), (4), (7) and (8) show results for two alternative time windows, namely 1 week and 4 weeks before/after the start of SMP, respectively. The variable "Yield increase pre-SMP" captures the yield increase of each bond in the 4 weeks pre-SMP (from April 12 to May 7), measured in percentage points. Robust standard errors clustered by bond are reported in parentheses. ***/**/* indicates significance at a 1%, 5%, and 10% level, respectively.

	ECB intervention measured by target dummy				**ECB intervention measured by ECB holdings**			
	8-week		**1-week**	**4-week**	**8-week**		**1-week**	**4-week**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Post-SMP indicator	-2.89***	-4.30***		3.01***	-4.91***	-5.05***		1.97***
	(1.08)	(1.12)		(0.62)	(1.04)	(1.04)		(0.52)
ECB intervention x post-SMP indicator /1	-2.76***	-1.74***	-2.01***	-2.45***	-0.12***	-0.10***	-0.10***	-0.13***
	(0.40)	(0.52)	(0.37)	(0.49)	(0.01)	(0.02)	(0.02)	(0.02)
CDS premia	1.52***	1.86***	0.75***	2.06***	1.80***	1.85***	0.80***	2.10***
(in %, by maturity)	(0.14)	(0.14)	(0.27)	(0.18)	(0.16)	(0.16)	(0.27)	(0.17)
Yield increase pre-SMP x		-0.25***	-0.47***	-0.24***		-0.06	-0.29***	-0.02
post-SMP indicator		(0.05)	(0.06)	(0.05)		(0.08)	(0.09)	(0.07)
Constant	1.74***	0.72**	8.02*	-7.21***	1.04**	0.83*	7.16**	-4.51***
	(0.33)	(0.34)	(2.97)	(1.88)	(0.44)	(0.43)	(3.00)	(1.52)
Observations	2,920	2,920	407	1,507	2,920	2,920	407	1,507
Number of bonds	37	37	37	37	37	37	37	37
Adjusted R^2	0.846	0.869	0.887	0.811	0.877	0.878	0.887	0.820

/1 Either target dummy variable (columns 1-4) or share of ECB purchases in each series (in % of total face value, columns 5-8).

Table 7: Robustness - panel estimations on the effects of bond purchases

This table reports differences-in-differences-type estimators of the effect of ECB bond purchases on bond yields (in percentage points). Columns (1) to (3) expand our main panel analysis (Table 6 above). Column (1) accounts for ECB purchases of close substitute bonds, meaning bonds within 2 years maturity of the bond's own maturity (1 year more or 1 year less), expressed as share of total bonds outstanding in the respective maturity bucket in percentage points. Column (2) uses yield spreads above German Bunds as dependent variable (in percentage points), instead of absolute yields, as in all other specifications. Column (3) shows results for a weighted least regression using total bond amount outstanding (in € bn) as weighting parameter. Columns (4) to (7) show results of fixed effect panel regressions based on a two-period panel. The dependent variable is the average bond yield in percentage points for various time windows before and after the start of the SMP on May 10. Column (4) is based on average yields in the 8 weeks before (first time period) and 8 weeks after (second time period) the start of the SMP. Columns (6) and (7) show results for two alternative time windows, namely 1 week and 4 weeks before/after the start of SMP, respectively. The post-SMP indicator is a dummy that is 1 after the start of the SMP on May 9. The ECB target variable is a dummy indicating whether the ECB purchased bonds in that bond series. Robust standard errors clustered by bond are reported in parentheses. ***/**/* indicates significance at a 1%, 5%, and 10% level, respectively.

	Daily Panel (8-week)			**2-period Panel**		
	With Close Substitutes	**With Yield Spreads**	**Weighted LS**	**8-week average**	**1-week average**	**4-week average**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Post-SMP Indicator	-3.36***	-3.79***	-1.69*	-1.20	2.17***	2.68***
	(1.00)	(1.11)	(0.94)	(1.27)	(0.62)	(0.68)
ECB Target (dummy) x post-SMP indicator	-2.60***	-1.78***	-1.98***	-1.40***	-1.65***	-2.61***
	(0.44)	(0.53)	(0.44)	(0.45)	(0.37)	(0.51)
CDS Premia	1.64***	1.88***	1.28***	0.03***	0.00	0.04**
(in %, by maturity)	(0.13)	(0.13)	(0.11)	(0.01)	(0.00)	(0.02)
Yield increase pre-SMP x	-0.03			-0.29***	-0.60***	-0.20***
post-SMP indicator	(0.02)			(0.06)	(0.07)	(0.08)
ECB purchases of close		-0.24				
substitutes x post-SMP indicator		(0.05)				
Constant	1.42***	-1.48***	1.97***	-4.06*	14.31***	-8.27
	(0.32)	(0.34)	(0.32)	(2.14)	(2.74)	(7.59)
Bond fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	No	No	No
Observations	2,920	2,920	2,920	74	74	74
Number of bonds	37	37	37	37	37	37
Adjusted R^2	0.848	0.903	0.903	0.832	0.943	0.696

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Appendix

Figure A1: Timeline of Total SMP purchases (ECB data)

This figure shows total sovereign bond purchases per week, in € mn of purchasing prices and as communicated by the ECB. The ECB provides no timeline of purchases by country.

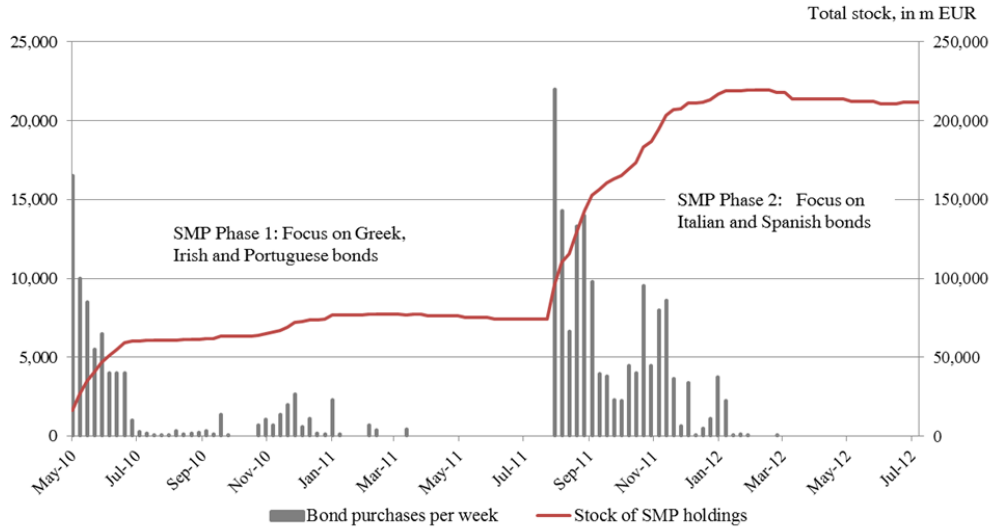

Figure A2: SMP purchases of Greek bonds in 2010 (estimates from Barclays 2012)

This figure shows estimates of weekly SMP purchasing volumes of Greek bonds in € mn of purchasing prices and taken from Barclays (2012). According to the data, the ECB purchased €36.4 bn of Greek bonds in the first 8 weeks of the programme. This corresponds to more than €40 bn at face value, or more than 95% of total ECB purchases of Greek bonds.

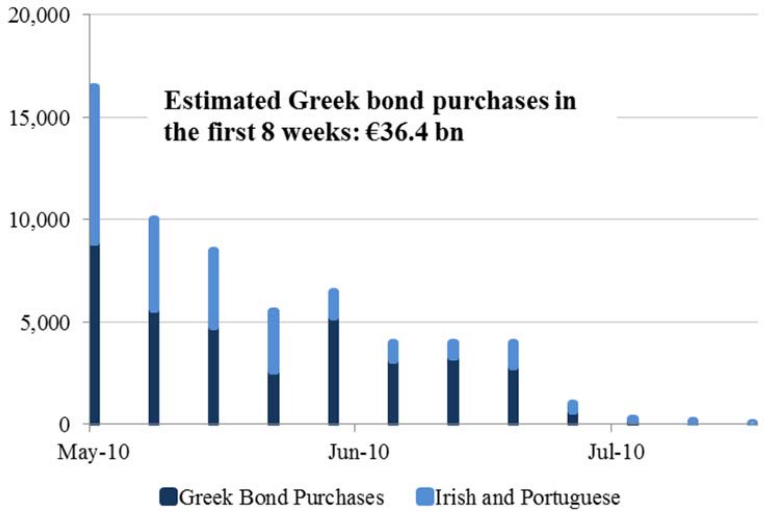

Table A1: List of all Greek sovereign bonds with ECB and NCBs holdings

ISIN	Maturity	Governing Law	Currency	Exchange	Total Volume Outstanding (€ mn, as of Febr. 2012)	Private Sector Holdings (€ mn, eligible for exchange)	NCBs Holdings (€ mn)	ECB Holdings (€ mn)	Share of ECB Holdings (in %)
GR0110021236	20.03.2012	Greek law	EUR	Athens	14435.0	9765.6	316.0	4273.2	29.6%
XS0147393861	15.05.2012	English law	EUR	Luxembourg	450.0	450.0	0.0	0.0	0.0%
GR0124018525	18.05.2012	Greek law	EUR	Athens	8000.0	4665.7	1220.3	2074.0	25.9%
GR0124020547	20.06.2012	Greek law	EUR	Athens	413.7	413.7	0.0	0.0	0.0%
GR0106003792	30.06.2012	Greek law	EUR	Athens	140.3	140.3	0.0	0.0	0.0%
GR0114020457	20.08.2012	Greek law	EUR	Athens	7720.0	4586.0	551.5	2517.4	32.6%
GR0326042257	22.12.2012	Greek law	EUR	Not Listed	2026.3	2026.3	0.0	0.0	0.0%
GR0508001121	31.12.2012	Greek law	EUR	Athens	22.9	22.9	0.0	0.0	0.0%
GR0512001356	20.02.2013	Greek law	EUR	Athens	5820.0	5376.7	302.0	121.3	2.1%
GR0110022242	31.03.2013	Greek law	EUR	Athens	36.4	36.4	0.0	0.0	0.0%
GR0124021552	20.05.2013	Greek law	EUR	Athens	9079.5	4490.6	1283.3	3288.6	36.2%
GR0128001584	20.05.2013	Greek law	EUR	Athens	2497.6	1492.7	225.3	779.6	31.2%
XS0372384064	25.06.2013	English law	USD	Frankfurt	1133.8	1083.9	49.7	0.0	0.0%
GR0124022568	03.07.2013	Greek law	EUR	n.a.	410.3	326.0	0.0	84.3	20.5%
CH0021839524	05.07.2013	Swiss law	CHF	SIX	538.4	538.4	0.0	0.0	0.0%
GR0110023257	31.07.2013	Greek law	EUR	Athens	64.3	64.3	0.0	0.0	0.0%
GR0114021463	20.08.2013	Greek law	EUR	Athens	5850.2	3680.2	268.0	1902.0	32.5%
GR0124023574	30.09.2013	Greek law	EUR	Athens	149.4	149.4	0.0	0.0	0.0%
GR0326043263	22.12.2013	Greek law	EUR	Not Listed	1854.7	1853.8	0.0	0.0	0.0%
GR0128002590	11.01.2014	Greek law	EUR	Athens	4552.1	2699.0	374.4	1424.8	31.3%
GR0124024580	20.05.2014	Greek law	EUR	Athens	8523.4	4368.7	1249.5	2868.3	33.7%
XS0097596463	21.05.2014	English law	EUR	Not Listed	70.0	69.0	0.0	1.0	1.4%
GR0124025595	01.07.2014	Greek law	EUR	Athens	424.0	394.0	0.0	30.0	7.1%
GR0112003653	25.07.2014	Greek law	EUR	Athens	155.4	155.4	0.0	0.0	0.0%
GR0114022479	20.08.2014	Greek law	EUR	Athens	12500.0	8541.2	393.0	3565.8	28.5%
GR0112004669	30.09.2014	Greek law	EUR	Athens	85.7	85.7	0.0	0.0	0.0%
GR0514020172	04.02.2015	Greek law	EUR	Athens	2020.0	2020.0	0.0	0.0	0.0%
JP530000CR76	14.07.2015	Japanese law	JPY	Not Listed	188.3	188.3	0.0	0.0	0.0%
GR0124026601	20.07.2015	Greek law	EUR	Athens	9584.9	6093.5	1360.5	2095.9	21.9%
GR0114023485	20.08.2015	Greek law	EUR	Athens	8000.0	4811.7	168.0	3020.3	37.8%
GR0114024491	30.09.2015	Greek law	EUR	Athens	171.4	171.4	0.0	0.0	0.0%
GR0124027617	10.11.2015	Greek law	EUR	Athens	375.0	375.0	0.0	0.0	0.0%
JP530000BS19	01.02.2016	Japanese law	JPY	Not Listed	282.4	282.4	0.0	0.0	0.0%
XS0165956672	08.04.2016	English law	EUR	Not Listed	400.0	400.0	0.0	0.0	0.0%
XS0357333029	11.04.2016	English law	EUR	Not Listed	5600.0	5547.2	30.0	22.8	0.4%
GR0516003606	21.05.2016	Greek law	EUR	Athens	170.3	170.3	0.0	0.0	0.0%
GR0124028623	20.07.2016	Greek law	EUR	Athens	7750.0	5442.4	821.8	1446.1	18.7%
JP530000CS83	22.08.2016	Japanese law	JPY	Not Listed	376.6	376.6	0.0	0.0	0.0%
GR0116002875	13.09.2016	Greek law	EUR	Athens	142.9	142.9	0.0	0.0	0.0%
XS0071095045	08.11.2016	English law	JPY	Not Listed	376.6	376.6	0.0	0.0	0.0%
GR0326038214	27.12.2016	Greek law	EUR	Athens	383.7	334.3	0.0	0.0	0.0%
GR0118014621	01.03.2017	Greek law	EUR	Not Listed	342.9	342.9	0.0	0.0	0.0%
GR0528002315	04.04.2017	Greek law	EUR	Athens	4985.0	4937.0	0.0	48.0	1.0%
GR0118012609	20.04.2017	Greek law	EUR	Athens	5000.0	3646.2	168.0	1185.8	23.7%
GR0518072922	01.07.2017	Greek law	EUR	Athens	415.5	415.5	0.0	0.0	0.0%
GR0518071916	01.07.2017	Greek law	EUR	Athens	71.6	71.6	0.0	0.0	0.0%
XS0078057725	03.07.2017	English law	JPY	Not Listed	282.4	282.4	0.0	0.0	0.0%
GR0124029639	20.07.2017	Greek law	EUR	Athens	11440.0	7562.5	1455.7	2412.2	21.1%
XS0079012166	08.08.2017	English law	JPY	Luxembourg	470.7	470.7	0.0	0.0	0.0%

Table A1 (Ct'd): List of all Greek Sovereign Bonds with ECB and NCBs Holdings

ISIN	Maturity	Governing Law	Currency	Exchange	Total Volume Outstanding (€ mn, as of Febr. 2012)	Private Sector Holdings (€ mn, eligible for exchange)	NCBs Holdings (€ mn)	ECB Holdings (€ mn)	Share of ECB Holdings (in %)
GR0118013615	09.10.2017	Greek law	EUR	Not Listed	214.3	214.3	0.0	0.0	0.0%
GR0120003141	03.04.2018	Greek law	EUR	Not Listed	444.0	440.0	0.0	0.0	0.0%
XS0260024277	05.07.2018	English law	EUR	Not Listed	2100.0	2086.0	0.0	14.0	0.7%
GR0124030645	20.07.2018	Greek law	EUR	Athens	7732.1	5875.8	590.5	1255.9	16.2%
XS0286916027	22.02.2019	English law	EUR	Not Listed	280.0	280.0	0.0	0.0	0.0%
GR0122002737	27.02.2019	Greek law	EUR	Athens	112.0	112.0	0.0	0.0	0.0%
GR0122003743	04.03.2019	Greek law	EUR	Not Listed	425.0	425.0	0.0	0.0	0.0%
IT0006527532	11.03.2019	Italian law	EUR	Milan	200.0	182.9	0.0	17.1	8.6%
XS0097010440	30.04.2019	English law	JPY	Not Listed	235.4	235.4	0.0	0.0	0.0%
XS0097598329	03.06.2019	English law	EUR	Not Listed	110.0	110.0	0.0	0.0	0.0%
GR0124031650	19.07.2019	Greek law	EUR	Athens	15500.0	11747.6	434.5	3318.0	21.4%
GR0120002135	17.09.2019	Greek law	EUR	Not Listed	350.0	350.0	0.0	0.0	0.0%
GR0133001140	22.10.2019	Greek law	EUR	Athens	8192.0	6175.0	561.9	1450.7	17.7%
GR0124032666	19.06.2020	Greek law	EUR	Athens	5000.0	3633.7	234.0	1132.4	22.6%
XS0224227313	13.07.2020	English law	EUR	Not Listed	250.0	250.0	0.0	0.0	0.0%
XS0251384904	19.04.2021	English law	EUR	Not Listed	250.0	250.0	0.0	0.0	0.0%
XS0255739350	31.05.2021	English law	EUR	Not Listed	100.0	100.0	0.0	0.0	0.0%
XS0256563429	09.06.2021	English law	EUR	Not Listed	150.0	150.0	0.0	0.0	0.0%
GR0133002155	22.10.2022	Greek law	EUR	Athens	8930.0	7623.3	767.9	539.3	6.0%
GR0133003161	20.03.2024	Greek law	EUR	Athens	10462.8	9156.9	215.0	1090.9	10.4%
XS0223870907	07.07.2024	English law	EUR	Not Listed	250.0	250.0	0.0	0.0	0.0%
XS0223064139	06.07.2025	English law	EUR	Not Listed	400.0	400.0	0.0	0.0	0.0%
GR0338001531	25.07.2025	Greek law	EUR	Athens	8648.4	8584.9	48.0	0.0	0.0%
GR0133004177	20.03.2026	Greek law	EUR	Athens	7000.0	6063.3	240.0	696.7	10.0%
XS0260349492	10.07.2026	English law	EUR	Not Listed	130.0	130.0	0.0	0.0	0.0%
XS0110307930	14.04.2028	English law	EUR	SIX	200.0	200.0	0.0	0.0	0.0%
GR0338002547	25.07.2030	Greek law	EUR	Athens	8344.9	8244.8	75.0	0.0	0.0%
XS0192416617	10.05.2034	English law	EUR	Not Listed	1000.0	1000.0	0.0	0.0	0.0%
XS0191352847	17.07.2034	English law	EUR	Frankfurt	1000.0	1000.0	0.0	0.0	0.0%
GR0138001673	20.09.2037	Greek law	EUR	Athens	9000.0	8867.2	116.0	16.8	0.2%
GR0138002689	20.09.2040	Greek law	EUR	Athens	7920.0	7920.0	0.0	0.0	0.0%
XS0292467775	25.07.2057	English law	EUR	Luxembourg	1778.4	1778.4	0.0	0.0	0.0%