# Safe Asset Carry Trade

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# Paper in a nutshell

Our understanding of the **asset pricing implications** and **economic determinants** of the temporal and cross-sectional variation in convenience premia is still limited.

We provide a **systematic asset pricing analysis** of one important category of safe asset, the repurchase agreement (repo).

- Standard **factor model** with a market factor (level) and a carry factor (slope) is able to price these near-money assets.
- **Carry factor** involves a long position in repos with higher rates and a simultaneous short position in repos with lower rates.

We rationalize our carry as the difference between **stable and wobbly convenience yields** provided by truly and quasi-safe assets.

- A simple framework and our empirical analyses show that our carry is explained by the **safety and liquidity premia** reflecting asset scarcity and opportunity cost.
- Our carry factor helps explain the cross-section of long-term **bond returns** after accounting for standard bond pricing factors.

# Contribution to literature

**Asset pricing**

- Common risk factors in equity, fixed income (Fama and French, 1993) and foreign exchange (FX) markets (Lustig, Roussanov, and Verdelhan, 2011). Koijen et al. (2018) on different carries in equity, fixed income, and option markets.
- Bond pricing literature of Cochrane and Piazzesi (2005) and Fontaine and Garcia (2012).

**Safe assets**

- Safe asset theories predicting cross-sectional dispersion in (quasi-) safe assets and convenience yields (e.g., Krishnamurthy, 2002; Krishnamurthy and Vissing-Jorgensen, 2012; Stein, 2012; Sunderam, 2015; Nagel, 2016; Caballero, Farhi, and Gourinchas, 2016; Moreira and Savov, 2017; Krishnamurthy, He, and Milbradt, 2019).
- Empirical literature (e.g., Longstaff, 2004; Fleckenstein, Longstaff, and Lustig, 2014; Greenwood and Vayanos, 2014; Krishnamurthy and Vissing-Jorgensen, 2015; Du, Im, and Schreger, 2018; and Kacperczyk, Perignon, and Vuillemey, 2021).

# Repo Market

# Data

European repo market is particularly **well suited** to analyzing the asset pricing implications and economic determinants of heterogeneous convenience premia.

- Euro repos are secured by government bonds with heterogeneous safety and liquidity attributes, thereby **broadening** the existing literature on convenience that largely concerns U.S. Treasuries.
- Market characteristics enable us to **isolate convenience yield** by eliminating many confounding factors such as term premia, counterparty and currency risk.
- **Largest** repo market worldwide and our data includes transactions covering more than 70% of the entire European repo market.

Breakdown of repo data

# Repo market

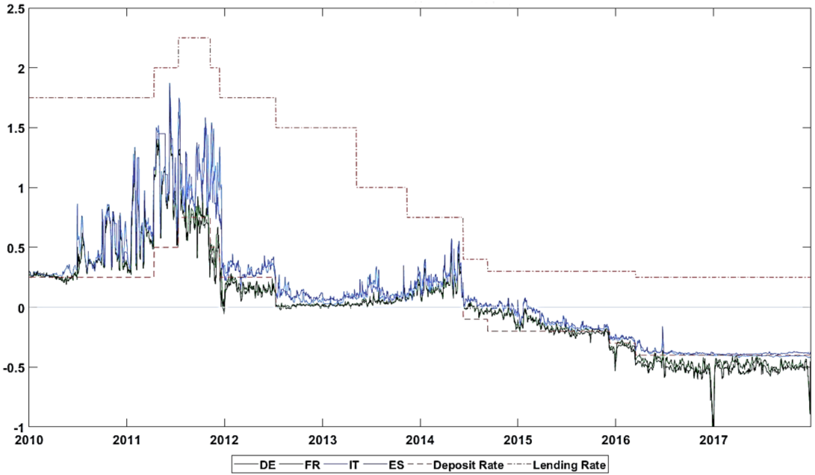


Figure: Repo Rate Development

# Carry Factor

# Safe asset portfolios

Consider portfolios consisting of the **entire repo market universe**.

At each trading day *t+1*, we allocate repos into **eight portfolios** based on the repo rate observed during the previous day *t*:

- **First** portfolio contains the repos with the **lowest** rate observed during the preceding trading day.
- **Last** portfolio contains the repos with the **highest** rate observed during the preceding trading day.

The carry return is ex-ante **unknown**.

Portfolios are **re-balanced daily**.

Account for **transaction cost**.

# Safe asset portfolios

Table: Portfolio Return

| **Portfolio** | **1** short | **2** long | **3** long | **4** long | **5** long | **6** long | **7** long | **8** long |
|---|---|---|---|---|---|---|---|---|
| Gross Return | 0.35 | −0.09 | −0.04 | −0.02 | 0.00 | 0.03 | 0.06 | 0.10 |
| Net Return | 0.29 | −0.12 | −0.06 | −0.04 | −0.02 | 0.01 | 0.05 | 0.08 |
| Standard Deviation (net) | 0.37 | 0.40 | 0.41 | 0.40 | 0.40 | 0.40 | 0.40 | 0.42 |
| Sharpe Ratio (net) | 0.78 | −0.29 | −0.15 | −0.09 | −0.04 | 0.03 | 0.12 | 0.20 |
| High-Minus-Low (net) | - | 0.17 | 0.23 | 0.25 | 0.27 | 0.30 | 0.34 | 0.37 |

The table shows the average, annualized portfolio returns for portfolios $n$=1, 2,...,8, gross and net of transaction cost; the standard deviation and Sharpe ratio of the net returns; as well as the return on the high-minus-low investment strategy, which shorts portfolio $n$=1 while going long in portfolios $n$=2, 3,...,8. The Sharpe ratio is defined as the annualized average over the annualized standard deviation.

# High-minus-low

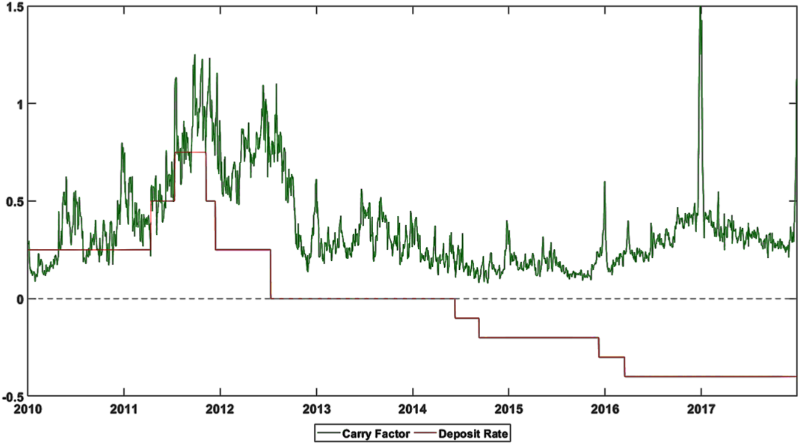


Figure: Development of the Safe Asset Carry Factor

# Robustness

Our results do not depend on **specialness** and **market segmentation**. Different carries

**Systemic clearing house risk** (Boissel et al., 2017) does not explain the existence of our carry ( Carry factor without GIIPS , CCP waterfall ). Carry return is largely driven by the low rates of repos secured by safe assets in portfolio 1.

Our carry factor remains positive and even increases after accounting for the **collateral return**. Bond collateral return

Overview robustness analyses

Country composition of carry

# Common Factors

# Principal component analysis

Table: Principal Component Analysis

| | PCA 1 | PCA 2 | PCA 3 | PCA 4 | PCA 5 | PCA 6 | PCA 7 | PCA 8 |
|---|---|---|---|---|---|---|---|---|
| *Portfolio 1* | 0.28 | -0.89 | 0.36 | 0.03 | 0.04 | -0.01 | 0.00 | -0.02 |
| *Portfolio 2* | 0.36 | -0.12 | -0.47 | -0.66 | -0.38 | -0.15 | -0.15 | 0.09 |
| *Portfolio 3* | 0.37 | -0.02 | -0.40 | -0.01 | 0.50 | 0.34 | 0.59 | 0.02 |
| *Portfolio 4* | 0.36 | 0.03 | -0.30 | 0.35 | 0.31 | 0.07 | -0.72 | -0.18 |
| *Portfolio 5* | 0.36 | 0.07 | -0.14 | 0.52 | -0.31 | -0.62 | 0.31 | -0.06 |
| *Portfolio 6* | 0.36 | 0.16 | 0.19 | 0.23 | -0.39 | 0.48 | -0.06 | 0.61 |
| *Portfolio 7* | 0.36 | 0.26 | 0.35 | -0.13 | -0.25 | 0.29 | 0.08 | -0.72 |
| *Portfolio 8* | 0.37 | 0.32 | 0.48 | -0.31 | 0.45 | -0.40 | -0.06 | 0.26 |
| **% Variance** | 94.97% | 4.26% | 0.57% | 0.10% | 0.04% | 0.03% | 0.02% | 0.02% |

# Asset pricing results

Table: GMM Estimation

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| **Portfolio** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | GMM |
| $a$ | −0.01 | 0.02*** | 0.02*** | 0.02*** | 0.02*** | 0.02** | 0.02*** | 0.02*** | |
| | (−1.45) | (4.25) | (5.13) | (6.89) | (7.08) | (2.38) | (6.53) | (5.91) | |
| $\beta^{Market}$ | 0.97*** | 1.06*** | 1.05*** | 1.03*** | 1.00*** | 0.98*** | 0.98*** | 0.99*** | |
| | (81.32) | (89.20) | (120.23) | (169.88) | (227.14) | (81.38) | (87.01) | (85.60) | |
| $\beta^{HML}$ | −0.89*** | −0.11*** | 0.03*** | 0.09*** | 0.13*** | 0.20*** | 0.28*** | 0.37*** | |
| | (−41.53) | (−11.61) | (3.30) | (8.63) | (12.00) | (9.69) | (28.65) | (30.58) | |
| $\lambda^{Market}$ | | | | | | | | | −0.07 |
| | | | | | | | | | (−1.64) |
| $\lambda^{HML}$ | | | | | | | | | 0.39*** |
| | | | | | | | | | (15.94) |
| $N$ | | | | | | | | | 16,392 |
| Time Periods | | | | | | | | | 2,049 |
| adj. $R^2$ | | | | | | | | | 97.73% |
| $\chi^2$ | | | | | | | | | 28.59% |

FMB estimation

# Economic Determinants

# Drivers of safe asset determination

Safe asset literature outlines **differences across (quasi-) safe assets** that make them imperfect substitutes (Sunderam, 2015).

"Specialness of safe assets implies the existence of nonpecuniary returns (called the convenience yield), in the form of **liquidity** or moneyness (the money-like property of NQA) and **safety**" (Gorton, 2017).[3]

We extend the framework proposed in **Krishnamurthy (2002)** to a larger and a more complex repo market in which collateral assets are featured by various degrees of safety and liquidity attributes. Theoretical framework

[3] A "safe asset" is an asset taken at face value with "no questions asked" (NQA).

# Economic interpretation

Carry reflects **differences in convenience yield** as truly safe assets (low-rate portfolio) carry higher safety and liquidity benefits than quasi-safe assets (high-rate portfolio).

- Carry return increases in the **safety premium** (i.e., difference in ten-year CDS spreads between the countries in the high- and low-rate portfolio). Scatterplot
- Carry return increases in **asset scarcity** reflecting one aspect of the liquidity premium (i.e., difference in the short-term debt to GDP ratio between the countries in the high- and low-rate portfolio). Scatterplot
- Carry return increases with the **opportunity cost** reflecting another aspect of the liquidity premium (i.e., main Euro-area short-term interest rate benchmark Eonia).

Control for market frictions and **arbitrage deviations** by accounting for the U.S. Dollar Euro covered interest parity (CIP) basis.

# Drivers of safe asset determination

Table: Economic Analysis: Safe Asset Dimensions

| Return Portfolio | (1)<br>1<br>b/t | (2)<br>2<br>b/t | (3)<br>3<br>b/t | (4)<br>4<br>b/t | (5)<br>5<br>b/t | (6)<br>6<br>b/t | (7)<br>7<br>b/t | (8)<br>8<br>b/t |
|---|---|---|---|---|---|---|---|---|
| Risk | -0.366*** | -0.080* | -0.064* | -0.079** | -0.085** | -0.030 | 0.073** | 0.071* |
| | (-3.20) | (-1.77) | (-1.73) | (-2.46) | (-2.78) | (-1.01) | (2.28) | (1.95) |
| Asset Supply | -0.256 | -0.065 | -0.044 | -0.013 | -0.008 | -0.027 | -0.008 | 0.008 |
| | (-1.40) | (-0.93) | (-0.76) | (-0.27) | (-0.17) | (-0.59) | (-0.17) | (0.14) |
| Opportunity Cost | 0.663*** | 0.917*** | 0.940*** | 0.939*** | 0.958*** | 1.008*** | 1.031*** | 1.077*** |
| | (7.90) | (19.46) | (25.32) | (27.91) | (30.95) | (33.97) | (51.10) | (45.18) |
| Arbitrage Deviations | -0.226** | -0.227*** | -0.220*** | -0.195*** | -0.152*** | -0.046 | -0.070*** | -0.020 |
| | (-2.29) | (-5.50) | (-6.48) | (-6.68) | (-5.46) | (-1.69) | (-2.85) | (-0.71) |
| Carry Lag1 | -0.296* | -0.031 | -0.025 | -0.009 | -0.014 | -0.054 | -0.163*** | -0.139*** |
| | (-2.04) | (-0.56) | (-0.55) | (-0.23) | (-0.38) | (-1.50) | (-3.78) | (-2.88) |
| Constant | 0.041 | -0.071 | -0.039 | -0.026 | -0.013 | -0.037 | -0.042** | -0.039* |
| | (0.57) | (-1.57) | (-1.11) | (-0.78) | (-0.44) | (-1.32) | (-2.67) | (-2.05) |
| $N$ | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| adj. $R^2$ | 0.867 | 0.946 | 0.967 | 0.971 | 0.976 | 0.979 | 0.996 | 0.994 |

# Drivers of safe asset determination

Table: Economic Analysis: Safe Asset Dimensions

| | (1) Carry b/t | (2) Carry b/t | (3) Carry b/t | (4) Carry b/t | (5) Carry b/t | (6) Carry b/t |
|---|---|---|---|---|---|---|
| Risk | 0.545*** | | | | 0.396*** | 0.396*** |
| | (6.63) | | | | (5.84) | (5.20) |
| Asset Supply | | 0.545** | | | 0.249** | 0.242* |
| | | (3.02) | | | (2.22) | (2.02) |
| Opportunity Cost | | | 0.319** | | 0.366*** | 0.357*** |
| | | | (2.35) | | (5.70) | (5.25) |
| Arbitrage Deviation | | | | 0.361*** | 0.166** | 0.159** |
| | | | | (3.35) | (2.49) | (2.31) |
| Carry Lag1 | | | | | | 0.019 |
| | | | | | | (0.21) |
| Constant | −0.035 | 0.131 | 0.372*** | 0.264** | −0.091 | −0.097 |
| | (−0.32) | (0.62) | (5.02) | (2.16) | (−1.62) | (−1.55) |
| $N$ | 31 | 31 | 31 | 31 | 31 | 30 |
| adj. $R^2$ | 0.589 | 0.213 | 0.131 | 0.254 | 0.803 | 0.791 |

# Drivers of safe asset determination

To **validate** our results, we perform a number of additional tests:

- For each term type, for GC and special repo transactions, and for trades executed on BrokerTec.
- At a daily frequency.
- For repo liquidity. Results
- By employing alternative measure for risk (CDS index of European Banks), asset supply (debt to GDP), opportunity cost (one-month Euribor and average repo market rate) and arbitrage constraints (TED spread, VIX, CISS, balance cost of holding government bonds).
- By accounting for any ECB purchases under the PSPP.

# Convenience Premium and Asset Prices

# Convenience premium and asset prices

Two repo factors help explain the **cross-section of bond returns** after accounting for the standard bond pricing factors and measures of bond safety and liquidity.

- Consider the cross-section of European sovereign bonds that are posted as repo collateral.
- Estimate daily yield curves following the yield curve representation introduced by Nelson and Siegel (1987) and by using German government bonds.

We relate the unexplained **yield component** to measures of bond safety, bond liquidity, and our two repo factors.

Carry Factor and First PCA of Unexplained Bond Return

Country Loadings on Carry Factor and Bond PCA

# Convenience premium and asset prices

Table: Convenience Premium and Bond Prices

| | (1) Bond Return b/t | (2) Bond Return b/t | (3) Bond Return b/t | (4) Bond Return b/t | (5) Bond Return b/t |
|---|---|---|---|---|---|
| Nelson-Siegel Implied Bond Return | 1.239*** | 1.148*** | 0.957*** | 0.918*** | 0.838*** |
| | (14.495) | (18.616) | (25.452) | (28.124) | (23.087) |
| Repo Carry Factor * | | | | | |
| Germany | | −0.001* | −0.002** | | −0.017*** |
| | | (−1.945) | (−2.333) | | (−5.515) |
| Netherlands | | 0.001 | 0.000 | | −0.015*** |
| | | (1.308) | (0.758) | | (−4.935) |
| Austria | | 0.006*** | 0.006*** | | −0.014*** |
| | | (8.733) | (8.802) | | (−3.737) |
| Finland | | 0.002*** | 0.002*** | | −0.011*** |
| | | (2.808) | (4.097) | | (−4.118) |
| Belgium | | 0.013*** | 0.013*** | | −0.008* |
| | | (6.632) | (6.373) | | (−1.951) |
| Spain | | 0.027*** | 0.027*** | | 0.008** |
| | | (24.157) | (24.780) | | (2.063) |
| Italy | | 0.029*** | 0.028*** | | 0.010*** |
| | | (45.231) | (57.898) | | (2.941) |
| Ireland | | 0.057*** | 0.056*** | | 0.024*** |
| | | (43.048) | (36.917) | | (4.105) |
| Portugal | | 0.097*** | 0.096*** | | 0.066*** |
| | | (14.287) | (14.146) | | (9.140) |
| Repo Market Factor | | | 0.007*** | | 0.004*** |
| | | | (3.546) | | (3.167) |
| Bond Safety | | | | 0.013*** | 0.012*** |
| | | | | (4.188) | (4.738) |
| Bond Liquidity | | | | 0.004*** | 0.003*** |
| | | | | (4.625) | (5.978) |
| $N$ | 614,667 | 614,667 | 614,667 | 614,665 | 614,665 |
| adj. $R^2$ | 0.741 | 0.855 | 0.858 | 0.863 | 0.910 |
| Bond FE | Yes | Yes | Yes | Yes | Yes |

# Conclusion

# Conclusion & outlook

We provide the **first systematic asset pricing analysis** of one of the main categories of safe assets, the repurchase agreement.

Rationalize the dispersion in rates captured by our carry with the idea that market participants **value the different convenience premia** embedded in truly and quasi-safe assets.

We propose a simple **theoretical framework** and provide **empirical evidence** that our carry factor is explained by the safety premia and the liquidity benefits, which vary with asset scarcity and opportunity cost.

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# Appendix: Repo data

Table: Breakdown of the Repo Data

| | Transactions (in mn) | Volume (in EUR tn) | Transactions (share in %) | Volume (share in %) |
|---|---|---|---|---|
| Centrally Cleared Euro Repos | 16.87 | 441.39 | 100.00% | 100.00% |
| General Collateral | 1.49 | 136.18 | 8.82% | 30.85% |
| Special Collateral | 15.38 | 305.21 | 91.18% | 69.15% |
| *of which are government bonds* | *15.38* | *305.19* | | |
| BrokerTec | 10.35 | 241.88 | 61.38% | 54.80% |
| Eurex | 0.27 | 56.06 | 1.61% | 12.70% |
| MTS | 6.24 | 143.45 | 37.01% | 32.50% |
| Overnight | 0.61 | 48.46 | 3.63% | 10.98% |
| Tomorrow-Next | 3.22 | 95.28 | 19.06% | 21.59% |
| Spot-Next | 13.04 | 297.65 | 77.31% | 67.44% |
| Austria | 0.71 | 10.88 | 4.49% | 2.59% |
| Belgium | 1.34 | 24.84 | 8.49% | 5.91% |
| Germany | 4.84 | 135.52 | 30.63% | 32.22% |
| European Union | 0.22 | 53.51 | 1.40% | 12.72% |
| Finland | 0.44 | 6.25 | 2.77% | 1.49% |
| France | 0.10 | 14.35 | 0.61% | 3.41% |
| Ireland | 0.31 | 3.49 | 1.99% | 0.83% |
| Italy | 6.26 | 143.24 | 39.68% | 34.06% |
| Netherlands | 1.12 | 22.86 | 7.08% | 5.44% |
| Portugal | 0.45 | 5.64 | 2.86% | 1.34% |
| Spain | 1.09 | 20.81 | 6.89% | 4.95% |

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# Appendix: Robustness overview

Table: Robustness Results

| Overview Online Appendix | | | |
|---|---|---|---|
| | Carry Factor | Common Factors | Economic Analysis |
| ON, TN, and SN Term Types | ***for ON:*** see OA.1.1.2; ***for TN:*** see OA.1.1.3; ***for SN:*** see OA.1.1.4; | ***for ON:*** see OA.2.1.1, OA.2.1.4, OA.2.1.7, OA.2.1.10; ***for TN:*** see OA.2.1.2, OA.2.1.5, OA.2.1.8, OA.2.1.10; ***for SN:*** see OA.2.1.3, OA.2.1.6, OA.2.1.9, OA.2.1.10; | ***for ON:*** see OA.3.1.1; ***for TN:*** see OA.3.1.2; ***for SN:*** see OA.3.1.3; |
| GC and Special Repos | ***for GC:*** see OA.1.2.1; ***for Special:*** see OA.1.2.2; | ***for GC:*** see OA.2.2.1, OA.2.2.3, OA.2.2.5, OA.2.2.7; ***for Special:*** see OA.2.2.2, OA.2.2.4, OA.2.2.6, OA.2.2.8; | ***for GC:*** see OA.3.2.1; ***for Special:*** see OA.3.2.2; |
| BrokerTec | ***for BrokerTec:*** see OA.1.3.1; | ***for BrokerTec:*** see OA.2.3.1, OA.2.3.2, OA.2.3.3, OA.2.3.4; | ***for BrokerTec:*** see OA.3.3.1; |
| Other Robustness Results | ***different portfolio sizes:*** see OA.1.1.1; ***portfolio composition by country:*** see OA.1.4.1–OA.1.4.8; | - | ***daily frequency:*** see OA.3.4.1; ***different variables:*** see OA.3.5.1–OA.3.5.9; ***ECB PSPP:*** see OA.3.6.1–OA.3.6.2; ***for bond return:*** see OA.3.7.1; ***for repo liquidity:*** see OA.3.8.1–OA.3.8.3; |

Tables OA.4.1.1–OA.4.2.3 contain additional robustness checks for our analysis of convenience yields and bond pricing.

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# Appendix: Different carries

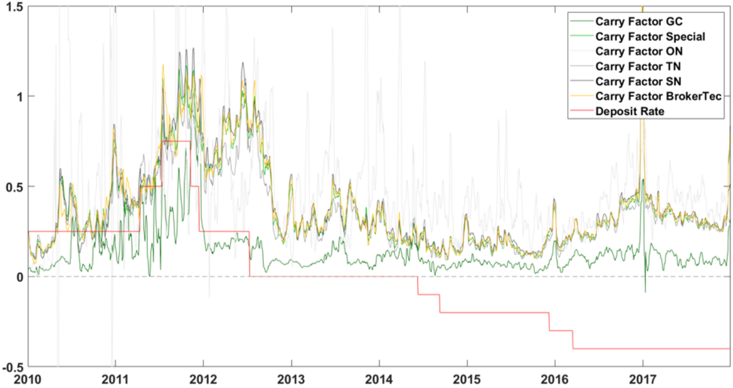


Figure: Development of Different Safe Asset Carry Factors

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# Appendix: Carry factor without GIIPS countries

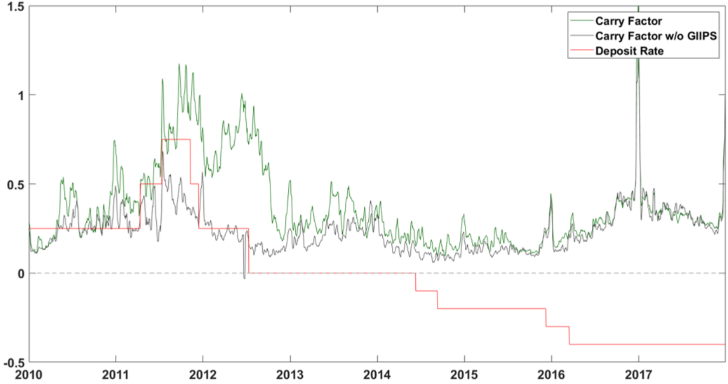


Figure: Development of the Safe Asset Carry Return with/without GIIPS Countries

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# Appendix: CCP waterfall

**Systemic risk of clearing houses** does not provide an explanation for the temporal and cross-sectional variations in repo rates.

Default would imply **overnight**

- (i) failure of **central counterparty members**,
- (ii) failure of **central counterparty** and
- (iii) **sovereign** distress/default.

Significant **capital buffers** and highly conservative **investment policies** by central counterparties, as well as **flight-to-safety** during crisis periods.

The European Securities and Markets Authority (**ESMA**) reports on CCP stress tests do not suggest any systemic risk inherent in European CCPs.

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# Appendix: Collateral return

Repo leg requires that the **collateral asset** is held before entering the borrowing position.

- Likelihood of holding or easily obtaining a given security depends on a bank's business model, size, and characteristics.
- Performance of our carry factor remains positive and even increases once we account for the bond portfolio return. Results

Focus on the repo market to benefit from the unique market setting that allows us to separate an **asset's convenience** from its financial return.

# Appendix: Collateral return

Table: Bond Portfolio Analysis

| | Buy-and-Hold | | Buy-and-Sell | |
|---|---|---|---|---|
| Year | Return | St. Dev. | Return | St. Dev. |
| 2010 | 1.60% | 0.01% | 4.14% | 2.40% |
| 2011 | 1.41% | 0.01% | 7.05% | 6.68% |
| 2012 | 2.51% | 0.03% | 7.24% | 8.72% |
| 2013 | 2.77% | 0.01% | 1.23% | 2.04% |
| 2014 | 2.59% | 0.00% | 2.80% | 2.11% |
| 2015 | 2.65% | 0.00% | 0.78% | 3.10% |
| 2016 | 2.70% | 0.00% | 6.32% | 3.72% |
| 2017 | 2.71% | 0.01% | 0.52% | 2.83% |

In the buy-and-hold approach, the hypothetical carry trader adds to his portfolio all the securities needed as collateral to establish the daily low-rate portfolio. After purchase, the bonds remain in the portfolio until expiration. In the buy-and-sell approach, the hypothetical carry trader buys and sells daily the securities needed to establish the high- and low-rate portfolios. The carry trader is therefore positively (negatively) exposed to price changes of the securities pledged (obtained) on (from) the (reverse) repo side, i.e., the low-rate (high-rate) portfolio. We account for coupon returns and funding cost in both approaches and for transaction cost in the buy-and-hold approach. For the funding cost, we consider the three-month (unsecured) Euribor rate since it implies that (i) the carry trader does not need to hold any additional collateral to finance the portfolio and (ii) the funding roll-over frequency is only quarterly. The buy-and-hold return is therefore defined as the yield to maturity of the bonds in the low-rate portfolio less funding and transaction cost. The buy-and-sell return is defined as the positive (negative) price changes of the low-rate (high-rate) portfolio, plus coupon returns and less funding cost. We add the coupon returns (which are also reflected in the yield to maturity) since the owner of a government bond remains the beneficial owner even if a security is pledged as collateral. Since both approaches require a list of securities as well as the time period for which the securities need to be held, we refer to the SN term type.

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# Appendix: Country composition

Table: Carry Factor - Portfolio Constituents

| **Portfolio** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** |
|---|---|---|---|---|---|---|---|---|
| Austria | 3.5% | 5.3% | 7.5% | 11.9% | 12.3% | 5.9% | 1.8% | 0.9% |
| Belgium | 11.3% | 11.7% | 11.8% | 14.4% | 21.5% | 10.6% | 2.8% | 1.2% |
| EU | 1.3% | 0.7% | 0.3% | 0.2% | 0.4% | 2.4% | 2.4% | 4.2% |
| Finland | 3.5% | 4.9% | 6.3% | 7.4% | 6.7% | 3.2% | 1.1% | 0.7% |
| France | 0.0% | 0.1% | 0.1% | 0.3% | 1.1% | 1.8% | 1.0% | 1.1% |
| Germany | 31.6% | 36.5% | 37.6% | 33.4% | 20.7% | 8.3% | 2.8% | 2.5% |
| Ireland | 7.3% | 3.0% | 1.8% | 1.5% | 2.1% | 3.2% | 2.5% | 6.6% |
| Italy | 10.7% | 12.6% | 11.0% | 9.9% | 14.9% | 38.0% | 67.3% | 59.0% |
| Netherlands | 5.4% | 10.6% | 14.3% | 13.4% | 8.7% | 4.1% | 1.3% | 0.6% |
| Portugal | 10.2% | 4.0% | 2.3% | 1.8% | 2.6% | 4.0% | 3.1% | 7.9% |
| Spain | 15.4% | 10.6% | 6.9% | 5.8% | 9.0% | 18.6% | 13.8% | 15.2% |

The table shows the average percentage that each country's collateral constitutes of the collateral in portfolios $n$=1, 2,...,8. On each day and for each portfolio, we compute the ratio of the number of collateral securities associated with a country relative to the total number of collateral securities in a portfolio. We compute the average of the daily shares for each country in each portfolio to account for changes in the number of portfolio constituents across time.

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# Appendix: Fama and MacBeth (1973)

"Classical“ **two-stage** estimation procedure:

$$R_{n,t} = \alpha_n + \beta_n^{Market} \cdot f_t^{Market} + \beta_n^{HML} \cdot f_t^{HML} + \epsilon_{n,t} \quad (1)$$

$$R_n = \beta_n^{Market} \cdot \lambda^{Market} + \beta_n^{HML} \cdot \lambda^{HML} + \zeta_n. \quad (2)$$

In the time-series regression 1, we determine the portfolios' **betas**, while in the cross-sectional regression 2, we determine the **factor premia** for the market and the carry.

# Appendix: Fama and MacBeth (1973)

Table: FMB Estimation

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| **Portfolio** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | FMB |
| $a$ | −0.02 | 0.00 | 0.02* | 0.03*** | 0.03*** | 0.01 | 0.01 | 0.01 | |
| | (−1.53) | (−0.17) | (1.84) | (3.68) | (4.04) | (1.46) | (1.00) | (1.32) | |
| $\beta^{Market}$ | 0.98*** | 1.05*** | 1.04*** | 1.03*** | 1.00*** | 0.98*** | 0.97*** | 0.98*** | |
| | (87.75) | (54.28) | (93.65) | (176.48) | (143.46) | (81.20) | (92.45) | (100.65) | |
| $\beta^{HML}$ | −0.84*** | −0.08* | 0.02 | 0.07** | 0.11*** | 0.22*** | 0.32*** | 0.40*** | |
| | (−18.32) | (−1.74) | (0.68) | (2.67) | (5.45) | (8.70) | (11.89) | (11.35) | |
| $\lambda^{Market}$ | | | | | | | | | −0.07 |
| | | | | | | | | | (−1.41) |
| $\lambda^{HML}$ | | | | | | | | | 0.40*** |
| | | | | | | | | | (13.28) |
| $N$ | 2,049 | 2,049 | 2,049 | 2,049 | 2,049 | 2,049 | 2,049 | 2,049 | 16,392 |
| Time Periods | | | | | | | | | 2,049 |
| adj. $R^2$ | 97.30% | 98.72% | 99.18% | 99.29% | 99.39% | 99.51% | 99.30% | 98.98% | 98.15% |

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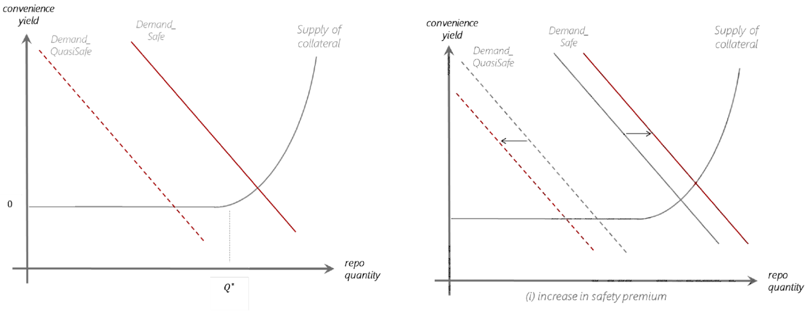
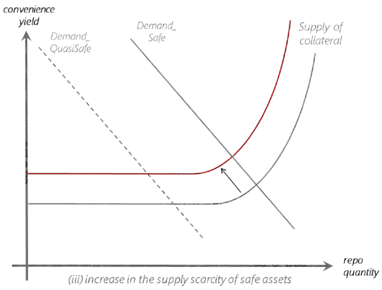
# Appendix: Convenience yield framework



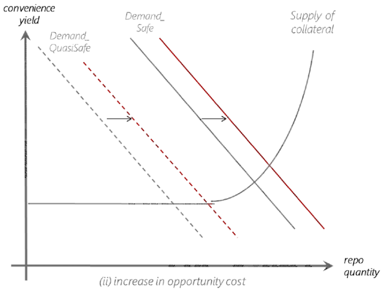

**(a)** Theoretical Framework **(b)** Safety premium

Figure: Convenience Yield Framework

# Appendix: Convenience yield framework




**(c)** Asset scarcity




**(d)** Opportunity cost

Figure: Convenience Yield Framework

# Appendix: Convenience yield framework

In our setting, the supply curve is given as

$$c(Q) = A + b^S \cdot X^S + d^S \cdot max[Q - Q^*, 0], \tag{3}$$

and the demand curve as

$$c(Q) = b^D \cdot X^D + b^R \cdot (\overline{Risk} - Risk^i) + b^L \cdot opportunitycost - d^D \cdot Q. \tag{4}$$

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# Appendix: Risk

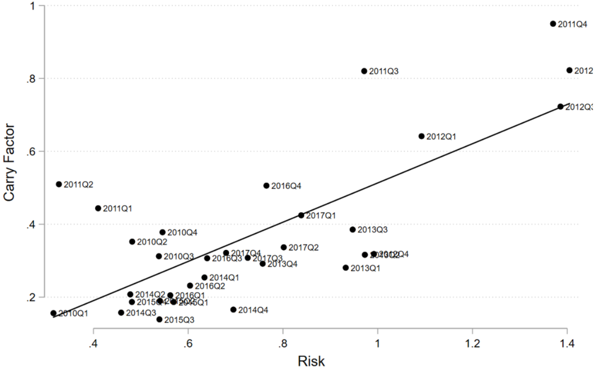


Figure: Scatterplot of the Carry Factor against Risk

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# Appendix: Asset supply

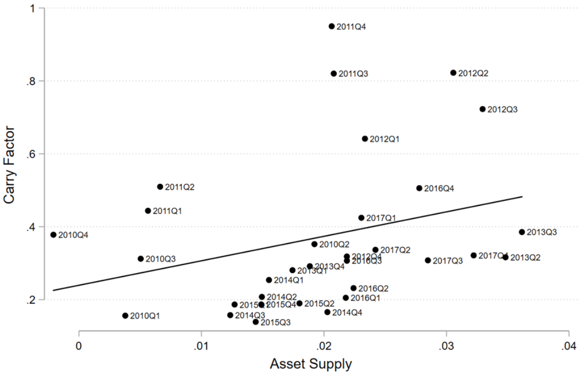


Figure: Scatterplot of the Carry Factor against Asset Supply

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# Drivers of safe asset determination

Table: Economic Analysis: Repo Market Liquidity

| | (1) Carry b/t | (2) Carry b/t | (3) Carry b/t | (4) Carry b/t | (5) Carry b/t | (6) Carry b/t |
|---|---|---|---|---|---|---|
| Risk | 0.274*** | | | | 0.280*** | 0.251*** |
| | (3.39) | | | | (4.61) | (4.35) |
| Repo Liquidity | | −0.659*** | | | −0.303** | −0.247* |
| | | (−3.99) | | | (−1.99) | (−1.70) |
| Opportunity Cost | | | 0.262** | | 0.238*** | 0.174*** |
| | | | (2.41) | | (3.38) | (3.15) |
| Arbitrage Deviations | | | | 0.183*** | 0.169*** | 0.184*** |
| | | | | (5.12) | (4.93) | (5.38) |
| Carry Lag1 | | | | | | 0.260*** |
| | | | | | | (3.12) |
| Constant | 0.183** | 0.452*** | 0.377*** | 0.320*** | 0.117** | 0.038 |
| | (2.03) | (5.97) | (5.11) | (3.14) | (2.01) | (0.92) |
| $N$ | 95 | 95 | 95 | 95 | 95 | 94 |
| adj. $R^2$ | 0.101 | 0.137 | 0.049 | 0.211 | 0.475 | 0.695 |

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# Convenience premium and asset prices

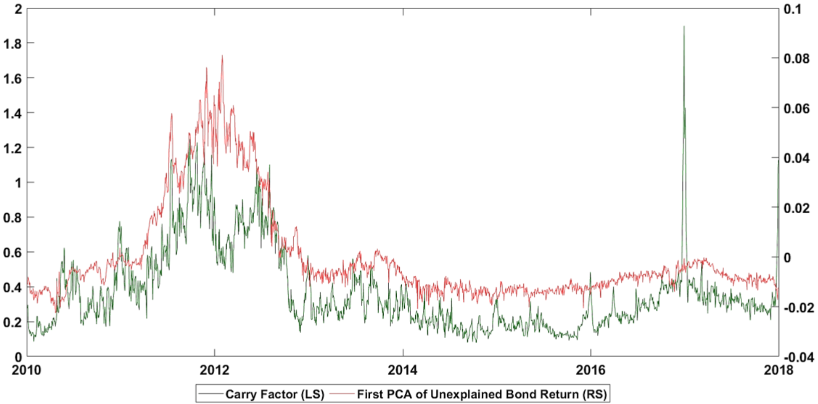


Figure: Carry Factor and First PCA of Unexplained Bond Return

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# Convenience premium and asset prices

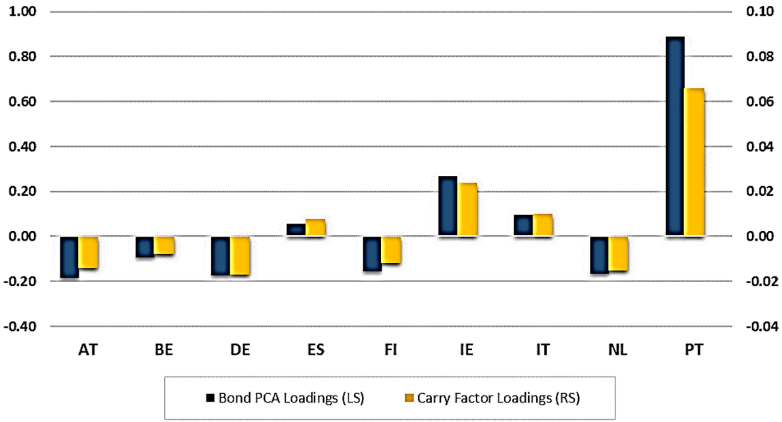


Figure: Country Loadings on Carry Factor and Bond PCA

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