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Green Bonds yield-to-worst during the pandemic: a VARX approach

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Abstract.

The paper is an investigation on the dynamic spillovers between the change of yield-to-worst of green bonds (ΔGREEN) and the change of market variables like brown bonds, stock, gold over the pandemic year. Our data refer to global issuers. Moreover, the study includes the General Fear Index (Salisu & Akanni, 2020), as a proxy of the market's fear for Covid. The analysis is conducted through a three lags VARX model, where the slope of the 5Y-1Y US Treasury bonds stands for the exogenous variable, in order to indicate the short-medium term liquidity of the market. We also make a comparison with the previous five years. Our main results, show that the impact of the change of the market fear for the pandemic is positively significant for each lag of the variable. Moreover, the exogenous one is significant for each endogenous variable in both periods of analysis. The Granger causality test shows a bi-directional predicting power between the change of green yield-to-worst and the change of brown bonds and gold while, with reference to the other variables, the test has a one-direction significant result from ΔGREEN to them. To the best of our knowledge this is the first study that adopts the yield-to-worst for the analysis of green bonds. The choice is justified by the aim to observe bonds in period of turmoil, like the pandemic year. We deem that our research could give useful information to sustainable investors, in order to make them aware of the worst market scenarios.

Keywords: green bonds, yield-to-worst, pandemic, market variables, GFI

1. Introduction

During the 2020, the year of the start of the Covid-19 pandemic, the sustainable debt market has shown a change in its composition, at the expense of green bonds. Specifically, the market has been characterized by a further split in its themes, on behalf to social, sustainable and pandemic bonds. At the same time, green bonds have shown an increasing demand and better performances compared to vanilla debt instruments. Notwithstanding, the market has had a discontinuous trend over the year in fact, if in the first quarter its volume has dropped lower than a half of 2019 (Climate Bonds Initiative, 2020), in the third quarter of 2020 green bonds have reached the highest volume of issuance for a third quarter, i.e. 69.4 bn USD (Climate Bonds Initiative, 2020).

Under a more general perspective, the role of the quantitative easing monetary policy of the Central Banks, in particular the Fed and ECB, has been crucial for the endurance of the global economy and of financial markets. Specifically, in emerging countries the impact seems to be much stronger and, at the same time, it's clear the need of country-specific interventions to affect local financial market conditions, even after controlling for common factors and spillovers from other countries (Rebucci et al., 2020). In the euro area, for instance, we recover the 1850 billion pandemic emergency purchase programme (PEPP) to lower borrowing costs and increase lending (ECB, 2020).

In this context, we focus our attention on the yield-to-worst (YTW) of green bonds. The yield-to-worst is the lowest yield a bond investor can gain if the bond does not default. More specifically, the yield-to-worst is also known as yield-to-call, in fact it is calculated in order to determine possible yields if a bond can be called by the issuer, reducing the amount of money the investor receives because the bond is not held to maturity. Compared to the classic yield-to-maturity (YTM), that implies the strong hypothesis of holding the bond until the maturity, the yield-to-worst seems to be a more realistic indicator, especially in times of market uncertainty.

The paper is an investigation on the dynamic spillovers between the daily change of yield-to-worst of green bonds (ΔGREEN) and the daily change of market variables like brown bonds, stock, gold over the pandemic year. Our data refer to global issuers. Moreover, the study includes the General Fear Index (Salisu & Akanni, 2020), as a proxy of the market's fear for Covid. The analysis is conducted through a three lags VARX model, where the slope of the 5Y-1Y US Treasury bonds stands for the exogenous variable, indicating the short-medium term liquidity of the market. We also make a comparison with the previous five years. Our main results, show that the impact of the change of the market fear for the pandemic is positively significant for each lag of the variable. Moreover, the exogenous one is significant for each endogenous variable in both periods of analysis. The Granger causality test shows a bi-directional predicting power between the change of green yield-to-worst and the change of

brown bonds and gold while, with reference to the other variables, the test has a one-direction significant result from ΔGREEN to them. To the best of our knowledge this is the first study that adopts the yield-to-worst for the analysis of green bonds. The choice is justified by the aim to observe bonds in period of turmoil, like the pandemic year. We deem that our research could give useful information to sustainable investors, in order to make them aware of the worst market scenarios.

2. Methods

The methodology adopted is a VARX model, i.e. a Vector Autoregressive Model that includes exogenous variables. **Equation 1** shows the general model in a matrix form:

$$Y_t = \alpha_k + \sum_{i=1}^{p} \Phi_{i,k}\ y_{t-i} + \Psi_k X_t + u_{i,t} \quad (1)$$

where:

Y_t = is the endogenous variables vector

Φ = is the matrix of the coefficients of the lagged variables

Ψ = is the matrix of the coefficients of the exogenous variables

X_t = is the exogenous variables vector

i = indicates the lag order

k = indicates the dependent variable

We apply this model both to the pandemic period, (f10th February 2020-2nd July 2021), and tothe previous five years (2nd January 2015-31st December 2019). We use daily data.

The common endogenous variables are the following ones:

GREEN= yield-to-worst of S&P Green Bonds Index

BROWN= performance of the S&P Bonds Index

STOCK= performance of the FTSE All-World Index

GOLD = gold futures

The common exogenous variable is SLOPE, i.e. the slope of the yield curve of US AAA government bonds[i] It is an indicator of general short-medium term market liquidity.

With reference to the only pandemic period, the model also includes a proxy of the market's fear for Covid. The variable, called GFI, is the Global Fear Index proposed by Salisu & Akanni(2020).[ii]

Our source of data are: S&P, FTSE, US Treasury, Datastream.

Below Figure 1 displays a graphic view of the green YTW of our sample over time, while Table1 shows the descriptive statistics the Jarque-Bera and the ADF test.

Figure 1: Green bonds YTW over time

Source: Authors' calculations

Pandemic year								
Variable	Mean	Min	Max	St. Dev.	Skewness	Kurtosis	JB test	**ADF**
GREEN	1.1013	0.73916	2.1154	0.26604	1.4542	1.9961	186.643***	**-3.394****
BROWN	519.86	445.30	539.99	16.804	-1.8075	3.9934	435.23***	**-3.115****
STOCK	393.69	253.51	477.60	54.604	-0.25627	-0.88526	15.6955***	**-0.581**
GOLD	1817.5	1491.0	2089.4	105.84	-0.23741	-0.059811	3.43559	**-1.968**
GFI	53.126	9.8863	91.047	10.453	1.1913	4.2955	361.917***	**-4.643*****
SLOPE	0.20967	-0.77000	0.90000	0.37933	-0.87925	1.2606	70.2208***	**-0.792**
Non-pandemic period								
GREEN	1.9015	1.2345	2.4392	0.31593	-0.11198	-0.99830	56.568***	**-1.283**
BROWN	426.46	387.70	491.29	25.869	0.73807	0.20780	120.091***	**1.281**

STOCK	305.53	233.43	374.30	33.487	-0.05802	-1.2867	90.198***	**-0.580**
GOLD	1336.0	1070.8	1593.3	95.539	0.2119	0.25912	13.3389***	**-3.307****
SLOPE	**0.59146**	**-0.37000**	**1.5200**	**0.46009**	**-0.1543**	**-0.83508**	**42.8338*****	**-1.498**

Table 1: Descriptive statistics, Normality and Unit-root test
Source: Authors' calculations.
****, **, and * indicate statistical significance at 1%, 5%, and 10% level, respectively.*

We adopt the selection order criteria test, to choose the lag of the variables of the model.

Table 2: Selection order criteria for pandemic year VARX

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	-1402.51		399.145	20.1787	20.2641	**20.3888**
1	-1320.43	164.16	176.676	19.3633	19.6621*	**20.0987***
2	-1301.27	38.325	192.367	19.4467	19.959	**20.7074**
3	**-1265.04**	**72.462***	**164.494***	**19.2862***	**20.012**	**21.0722**

Source: Authors' calculations.
****, **, and * indicate statistical significance at 1%, 5%, and 10% level,respectively.*

Table 2 shows the results of the tests for the pandemic period: three lags is the option that shows the highest number of significant tests.

Table 3: Selection order criteria for the previous period VARX

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	-2488.24		.20178	9.75093	9.77689	9.81716
1	-2416.17	144.13	.162094*	9.53193*	9.60981*	9.7306*
2	-2404.68	22.99	.164975	9.54953	9.67932	9.6793
3	-2391.3	26.747*	.166682	9.55979	9.7415	10.0234

Source: Authors' calculations.
****, **, and * indicate statistical significance at 1%, 5%, and 10% level,respectively.*

Table 3 shows the results of the tests for the pandemic period: in this case, one lag is the option that has the highest number of significant tests.

After adopting the Augmented Dickey-Fuller (ADF) test to control for the presence of unit roots, we calculate the first order of each variable to turn them all stationary.[iii]

3. Results

3.1 VARX Results

Table 4 shows the results of the VARX model applied for the pandemic period, i.e. from 10th February 2020 to 2nd July 2021.

Table 4: VARX Results for the pandemic year (10th February 2020-2nd July 2021)

	ΔGREEN	ΔBROWN	ΔSTOCK	ΔGOLD	ΔGFI
ΔGREEN (-1)	-.0430355	14.26405	67.0526**	198.1705	**-52.49689**
	(.118558)	(10.14301)	(29.44111)	(140.4874)	**(34.41999)**
	(-0.36)	(1.41)	(2.28)	(1.41)	**(-1.53)**
ΔGREEN (-2)	-.2680121***	28.89632***	14.4571	229.0812*	**-45.33244**
	(.1128162)	(9.651777)	(28.01526)	(133.6836)	**(32.75301)**
	(-2.38)	(2.99)	(0.52)	(1.71)	**(-1.38)**
ΔGREEN (-3)	.0012057	19.52814***	1.996988*	143.411	**-14.89373**
	(.0850177)	(7.27353)	(21.11216)	(100.7433)	**(24.68251)**
	(0.01)	(2.68)	(0.09)	(1.42)	**(-0.60)**
ΔBROWN (-1)	-.0027277*	.2328595*	.5513534	1.095535	**-.6184197**
	(.0014275)	(.122128)	(.3544888)	(1.691554)	**(.4144376)**
	(-1.91)	(1.91)	(1.56)	(0.65)	**(-1.49)**
ΔBROWN (-2)	-.0043228***	.3244011**	-.4455436	4.88784**	**-.8349797***
	(.0016085)	(.1376161)	(.3994449)	(1.906076)	**(.4669962)**
	(-2.69)	(2.36)	(-1.12)	(2.56)	**(-1.79)**
ΔBROWN (-3)	-.0024775	.3025066**	.5415125	5.346525***	**-.309339**
	(.0015344)	(.1312758)	(.3810413)	(1.818257)	**(.4454804)**
	(-1.61)	(2.30)	(1.42)	(2.94)	**(-0.69)**
ΔSTOCK (-1)	-.0010709***	.0318567	-.0504634	1.214092**	**-.0313093**
	(.0003996)	(.0341911)	(.0992432)	(.4735698)	**(.1160265)**
	(-2.68)	(0.93)	(-0.51)	(2.56)	**(-0.27)**
ΔSTOCK (-2)	-.0005119	.0350827	.14954	-.1881932	**.2273218***
	(.0004437)	(.0379563)	(.1101722)	(.5257208)	**(.1288037)**
	(-1.15)	(0.92)	(1.36)	(-0.36)	**(1.76)**
ΔSTOCK (-	-.0004799	.1114178**	.3888834**	-.4975007	**.1572101**

3)		*	*		
	(.000366)	(.0313145)	(.0908935)	(.4337267)	**(.1062648)**
	(-1.31)	(3.56)	(4.28)	(-1.15)	**(1.48)**
ΔGOLD (-1)	.0001663**	-.0230988***	.0099519	-.2211916**	**-.0407502***
	(.0000772)	(.0066008)	(.0191595)	(.0914257)	**(.0223997)**
	(2.16)	(-3.50)	(0.52)	(-2.42)	**(-1.82)**
ΔGOLD (-2)	-.0001517**	.0087951	.0252906	.081848	**-.0195002**
	(.0000753)	(.0064433)	(.0187023)	(.089244)	**(.0218651)**
	(-2.01)	(1.36)	(1.35)	(0.92)	**(-0.89)**
ΔGOLD (-3)	-.0000572	.0135836**	.0025533	.0566167	**-.0293612**
	(.0000656)	(.0056161)	(.0163014)	(.0777873)	**(.0190582)**
	(-0.87)	(2.42)	(0.16)	(0.73)	**(-1.54)**
ΔGFI (-1)	.0006429*	-.044246	-.0221652	.6087527	**-1.130763*****
	(.0003844)	(.0328835)	(.0954476)	(.4554582)	**(.1115891)**
	(1.67)	(0.178)	(-0.23)	(1.34)	**(-10.13)**
ΔGFI (-2)	.0012893** (.0005286) (2.44)	-.1106793** (.0452212) (-2.45)	-.0807906 (.1312591) (-0.62)	.0258649 (.6263435) (0.04)	**-.2661734* (.1534567) (-1.73)**
ΔGFI (-3)	.0008893***	-.0872308***	-.1213172*	-.1352162	**-.0303925**
	(.0002722)	(.0232901)	(.0676019)	(.3225836)	**(.0790343)**
	(3.27)	(-3.75)	(-1.79)	(-0.42)	**(-0.38)**
ΔSLOPE	.2185043***	-25.63911***	11.30452	-125.3313**	**8.476544**
	.0484046	(4.141161)	(12.02014)	(57.35785)	**(14.0529)**
	4.51	(-6.19)	(0.94)	(-2.19)	**(0.60)**
Cons	-.0017689	.0608715	-.3845823	-1.271893	**-.5296028**
	(.0015042)	.1286875	(.3735286)	(1.782408)	**(.4366972)**
	(-1.18)	0.47	(-1.03)	(-0.71)	**(-1.21)**

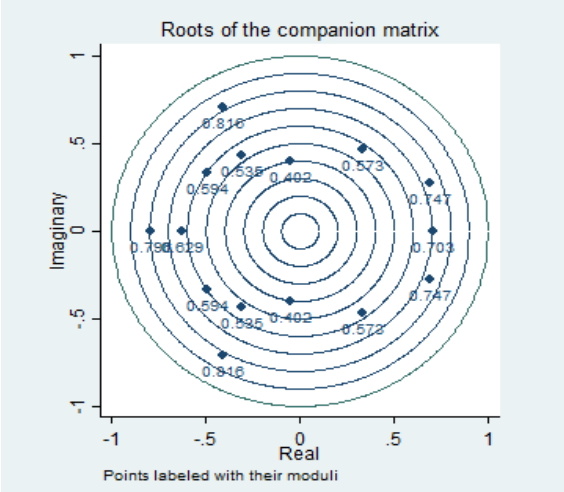
Num.of obs.= 140

Log likelihood = -1265.036

*Source: Authors' calculations. In parentheses are indicated, respectively, the standard error and the z value; ***, **, and * indicate statistical significance at 1%, 5%, and 10% level, respectively.*

The model is stable, as shown by Figure 2 below.

Figure 2: Stability check test for pandemic period VARX



Source: Authors' elaborations

As concerns the significant results for the change of the yield-to-worst of green bonds (ΔGREEN), there is a negative impact of the two days lag of the variable itself. We note the negative spillovers of one day and two days lagged changes of brown bonds (ΔBROWN). There is a 1% significant negative impact of the one day change of the stock variable (ΔSTOCK), while there are a positive and a negative impacts made, respectively, by the one day and the two days lagged change of the gold variable (ΔGOLD). The spillover of the change of the market fear for the pandemic (ΔGFI) is positively significant for each lag of the variable: in particular, the third lag seems to be significant at 1%. Finally, the change of the exogenous variable, namely the slope of Treasury bonds curve (ΔSLOPE), has a positive significant impact on ΔGREEN. ΔSLOPE variable, at the same time, has negative significant spillovers on ΔBROWN and ΔSTOCK.

Looking to the impacts of the change of yield-to-worst (ΔGREEN) on the other variables, we highlight that there is a positive spillover of the one day lag on ΔSTOCK, while the two days lagged ΔGREEN is positively significant for ΔBROWN (1%) and (ΔGOLD). The three days lagged yield-to-worst, is significant for ΔBROWN (1%) and ΔSTOCK (10%).

As concerns the impact of the change of the Global Index Fear (ΔGFI) on the other variables, we note that the two days lag and the three days'one have negative spillovers on ΔBROWN, respectively, at 5% and 1%. Finally, the three days lagged ΔGFI has a 10% significant negative impact on the change of stock.

The results of the VARX model applied to the previous five years, i.e. from 2nd January 2015-31st December 2019, are shown in Table 6 below.[iv]

Table 5: VARX Results for the previous five years (2nd January 2015-31st December 2019)

	ΔGREEN	**ΔBROWN**	**ΔSTOCK**	**ΔGOLD**
ΔGREEN (-1)	-.0990656***	-.3193793	-2.565721	**-79.05309*** **
	(.0307918)	(.8757743)	(2.568485)	**(20.64243)**
	(-3.22)	(-0.36)	(-1.00)	**(-3.83)**
ΔBROWN (-1)	-.004225***	.0484998*	.0290626	**.6004983**
	(.0008926)	(.025386)	(.0744524)	**(.5983598)**
	(-4.73)	(1.91)	(0.39)	**(1.00)**
ΔSTOCK (-1)	-.0012337***	.0742601***	(.1310791)***	**.1243541**
	(.0003738)	(.0106315)	(.0311803)	**(.2505904)**
	(-3.30)	(6.98)	(4.20)	**(0.50)**
ΔGOLD (-1)	.0000251	-.0007842	.0043133	**-.3985015*** **
	(.000035)	(.0009955)	(.0029197)	**(.0234654)**
	(0.72)	(-0.79)	(1.48)	**(-16.98)**
ΔSLOPE	.3882319***	-21.76961***	15.03854***	**-80.5408*** **
	(.0217251)	(.617902)	(1.812193)	**(14.56426)**
	(17.87)	(-35.23)	(8.30)	**(-5.53)**
Cons	.0002929	.0347729*	.1004489*	**1.401602*** **
	(.0007222)	(.020541)	(.0602429)	**(.484161)**
	(0.41)	(1.69)	(1.67)	**(2.89)**
Num.of obs = 1033				
Log likelihood = -4974.31				

Source: Authors' calculations.
In parentheses are indicated, respectively, the standard error and the z value;
****, **, and * indicate statistical significance at 1%, 5%, and 10% level, respectively.*

With reference to this period of analysis, we note that the one day lagged ΔGREEN, affects negatively the variable itself and ΔGOLD. The lagged brown bonds variable, instead, has a positive influence on ΔBROWN itself, but a 1% significant negative impact on ΔGREEN. As concerns the one day lagged ΔSTOCK, we highlight that it is negatively significant for ΔGREEN (1%) and has a positive significance at 1% for the variable itself and for ΔBROWN. The lagged gold variable has only a 1% negative impact on itself. Finally, we note that over the non-pandemic period, the exogenous variable is significant for all the endogenous ones and shows positive signs for ΔGREEN and ΔSTOCK and negative ones for ΔBROWN and ΔGOLD.

3.2 Granger causality test

Table 6: Granger causality test for both periods

Null Hypothesis	Pandemic F-statistic	Non-pandemic F-statistic
ΔGREEN does not Granger cause ΔBROWN	18.212***	**22.407*** **
ΔGREEN does not Granger cause ΔSTOCK	11.947***	**10.892*** **
ΔGREEN does not Granger cause ΔGOLD	10.619***	**.51398**
ΔGREEN does not Granger cause ΔGFI	13.839***	
ΔBROWN does not Granger cause ΔGREEN	17.892***	**.13299**
ΔBROWN does not Granger cause ΔSTOCK	15.697***	**48.789*** **
ΔBROWN does not Granger cause ΔGOLD	21.624***	**.62047**
ΔBROWN does not Granger cause ΔGFI	16.211***	
ΔSTOCK does not Granger cause ΔGREEN	5.5354	**.99785**
ΔSTOCK does not Granger cause ΔBROWN	6.522*	**.15237**
ΔSTOCK does not Granger cause ΔGOLD	1.9681	**2.1824**
ΔSTOCK does not Granger cause ΔGFI	3.2247	
ΔGOLD does not Granger cause ΔGREEN	7.044*	**14.666*** **
ΔGOLD does not Granger cause ΔBROWN	20.304***	**1.0072**
ΔGOLD does not Granger cause ΔSTOCK	7.0461*	**.24626**
ΔGOLD does not Granger cause ΔGFI	2.1412	
ΔGFI does not Granger cause ΔGREEN	4.6824	
ΔGFI does not Granger cause ΔBROWN	7.6677*	
ΔGFI does not Granger cause ΔSTOCK	4.8002	
ΔGFI does not Granger cause ΔGOLD	**5.8813**	

Source: Authors' elaborations.

****, **, and * indicate statistical significance at 1%, 5%, and 10% level,respectively.*

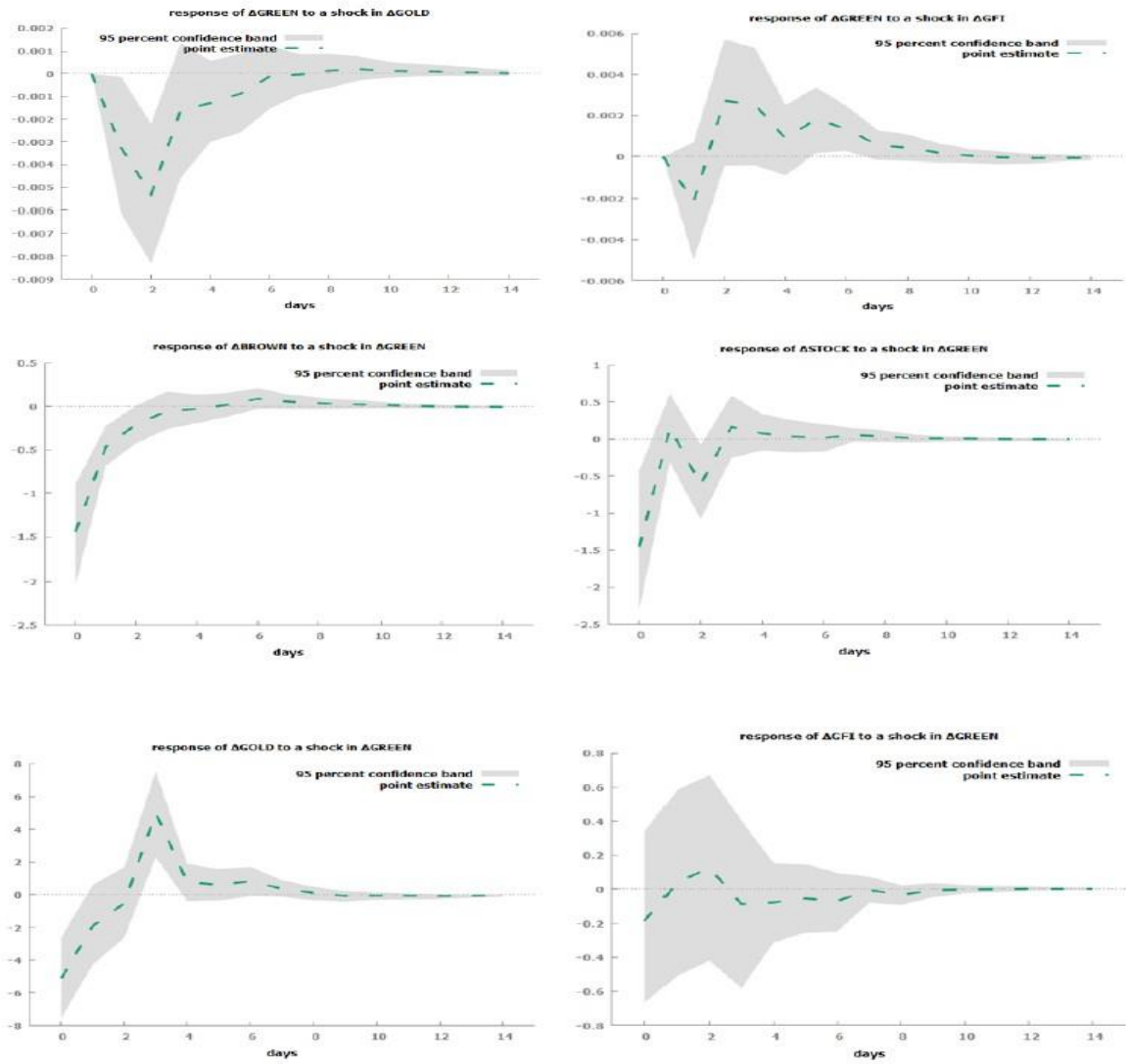
Table 6 shows the results of the Granger causality test, applied in order to verify the ability of each variable to predict the other ones. Focusing on the ΔGREEN variable over the pandemic period, we note that it Granger causes all the other variables, while only ΔBROWN is able to

predict ΔGREEN at 1%. ΔGOLD Granger causes ΔGREEN at 10%, while the test is not significant with reference to ΔSTOCK and ΔGFI.

3.3 Impulse Response Function (IRF)

Figure 2 displays the graphical Impulse Response Functions during the pandemic year, in order to show the response of ΔGREEN to shocks of the other variables and viceversa. The analysis is conducted over a 15 days horizon. We note that all variables, on average, turn to equilibrium in a week.

Figure 2: *Graphical IRF: shocks of other variabl es to ΔGREEN and viceversa*



Source: Authors' elaborations

4. Discussion

At a first glance, looking to Table 1, we note that the green bonds YTW and the brown index are not stationary in level during the pandemic year, but the ADF test is not significant in the previous period: this is consistent with a time of distress.[v] While the STOCK and the SLOPE variables are stationary in both cases, GOLD is stationary only during the pandemic: maybe this fact could be explained by the role that this commodity has had as safe-haven asset, at least on the first phase of the crisis (Akhtaruzzaman et al., 2021). As expected, the GFI is non-stationary.

Focusing on ΔGREEN , we deem interesting highlighting that during the pandemic year the spillovers from this variable and ΔBROWN are positive for the second and third lag, suggesting that higher risk in the green market, implies the choice for alternative investments, like brown bonds. At same time, we note a negative spillover from ΔBROWN to ΔGREEN and this result is analogous during the non-pandemic year. So higher values of brown bonds seem to lower therisk perception of the green market. The Granger causality test testifies that during the pandemicthere is a bi-directional predicting power of the two variables, while during the previous five years only ΔGREEN Granger causes ΔBROWN. The change of connectedness between the twomarkets over time is also testified by Arif et al. (2021), who furthermore observe higher connection during the pandemic.

The relation with the stock market, instead, shows a one day negative lagged spillover from the latter to ΔGREEN, while the change of the green yield-to-worst has positive spillovers to ΔSTOCK. The last result is consistent with Dutta et al. (2021) who find negative correlations between the stock market and the price of green bonds.

With refence to the green YTW and gold, we note that the spillovers are not always of the same sign during the pandemic: our finding is similar to Naeem et al. (2021) who find mixed results between the two variables.

As concerns ΔGFI we note spillovers to the bond market, both green and brown, respectively with reference to all three and to the second and third lags. The stock market needs three days of lag to be affected by the change of the fear index, while gold receives spillovers in one and two days of lag.

Finally, the significance of the exogenous variable expresses the importance of the general level of market liquidity.

5. Conclusion

The paper has analysed the dynamic spillovers between the green bonds yield-to-worst and market variables during the pandemic period, with a comparison to the previous five years.

Specifically, we have adopted a VARX model, with the slope of the yield curve of US AAA government bonds as exogenous variable. For the pandemic year, we have also included the GFI (Salisu & Akanni, 2020), as a proxy of the market sentiment during this period. Among the main results, we highlight the change of connectedness between green and brown bonds over time and the impact of the GFI index on the green bond risk.

We deem that the added value of our work is the choice of the yield-to-worst for the study of green bonds during a period of distress. This variable, in fact, considers the possibility that the issuer recalls the bond, so does not contemplate the strong hypothesis of holding it until the maturity, implied by the YTM. We think that observing the YTW could give useful informationto sustainable investors, especially in times of high uncertainty, when green bonds seem to losepart of the hedging power they have shown in times of less turbulence (Pham & Nguyen, 2021). Starting from the global perspective of the present study, the research could be proceeded adopting the same model for the comparison between the European, American and Asian markets.

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[i] The slope has been calculated as the difference between the 5 Years and the 1 Year US AAA government bonds yield curve.

[ii] The index is calculated as GFI= $[0.5(RCI_t+RDI_t)]$, where RCI is the Reported Cases Index and RDI is the Reported Deaths Index. The GFI has been calculated using data taken from www.ourworldindata.com.

[iii] We have verified with a second ADF test that the non-stationary variables are I(1). As displayed by Table 1, some variables are stationary in level; however we have calculated the first difference for each one, in order to homogenise the variables of the model.

[iv] The GFI variable is missing, as this a non-pandemic period.

[v] Yi et al. (2021) verify that during the pandemic the green bonds have registered abnormal returns.