Measuring high-frequency causality between returns, realized volatility and implied volatility: Empirical appendix *

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1. Introduction

This document contains detailed as well as complementary results, discussed in Dufour, Garcia and Taamouti (2010). The latter paper mainly presents figures which compare different causal effects between returns and volatility across horizons. To save space, confidence intervals are not included in Dufour et al. (2010). Here, both point estimates and confidence intervals on causality measures at different horizons are presented.

Section 2 contains descriptive and summary statistics, while the following sections present detailed causality profiles at different horizons. The confidence intervals are computed following different bootstrap techniques, namely the residual bootstrap technique described in Dufour and Taamouti (2010) and the fixed-design wild bootstrap proposed by Gonçalves and Kilian (2004). For the first method, summary results are presented in section 3, while section 4 contains more detailed results. The analysis in Dufour et al. (2010) focuses on these results. This method assumes that model innovations are homoskedastic. To allow for the possibility of heteroskedasticity, we present in section 5 confidence intervals based on a fixed-design wild bootstrap. The main finding is that the results based on the latter method differ very little from the results obtained by the residual bootstrap.

2. Data summary statistics

In this section, we present here basic summary statistics and graphs for the data used in the paper. Table 1 contains summary statistics for the five-minute, hourly, and daily returns of the S&P 500 futures index. Table 2 presents the descriptive statistics for hourly and daily realized volatility, bipower variation and measure of the contribution of jumps to total price variation. Table 3 shows the descriptive statistics for the daily implied volatility ($IV^{1/2}$), squared implied volatility (IV) and logarithm of squared implied volatility ($\ln(IV)$). The daily prices, returns and volatilities are displayed in Figures 1 and 2. Finally, the results of testing for jumps in our data are plotted in Figure 3.

Table 1. Summary statistics for S&P 500 futures returns,1988-2005

$Variables$	$Mean$	$St.Dev.$	$Median$	$Skewness$	$Kurtosis$
$Five$-minute	0.0000069	0.000978	0.00000000	−0.0818	73.9998
$Hourly$	0.0000131	0.003100	0.00000000	−0.4559	16.6031
$Daily$	0.0001466	0.008900	0.00011126	−0.1628	12.3714

Note: This table summarizes the five-minute, hourly, and daily returns distributions for the S&P 500 index contracts.

Table 2. Summary statistics for hourly and daily volatilities, 1988-2005

$Variables$	$Mean$	$St.Dev.$	$Median$	$Skewness$	$Kurtosis$
Hourly					
RV_t	0.00001080	0.0000294	0.00000544	42.9510	3211.190
BV_t	0.00000932	0.0000229	0.00000455	32.1242	2023.507
$\ln(RV_t)$	−12.2894	1.1475	−12.3006	0.0792	3.3157
$\ln(BV_t)$	−12.1007	1.0973	−12.1217	0.1558	3.2625
J_{t+1}	0.2258	0.2912	0.1221	2.0066	8.8949
Daily					
RV_t	0.0000813	0.000120	0.0000498	8.1881	120.7530
BV_t	0.0000762	0.000109	0.0000469	6.8789	78.9491
$\ln(RV_t)$	−9.8582	0.8762	−9.9076	0.4250	3.3382
$\ln(BV_t)$	−9.9275	0.8839	−9.9663	0.4151	3.2841
J_{t+1}	0.0870	0.1005	0.0575	1.6630	7.3867

Note: This table summarizes the hourly and daily volatilities distributions for the S&P 500 index contracts.

Table 3. Summary statistics for daily implied volatilities, 1996-2005

$Variables$	$Mean$	$St.Dev.$	$Median$	$Skewness$	$Kurtosis$
$IV_t^{1/2}$	1.1808	0.8225	1.0205	3.4518	30.5778
IV_t	2.0705	5.1356	1.0415	17.8220	484.6803
$\ln(IV_t)$	−0.0326	1.1980	0.0406	0.0676	3.0002

Note: This table summarizes the daily implied volatilities distributions for the S&P 500 index contracts.

Figure 1. Daily prices and returns of the S&P 500 futures. January 1988 to December 2005.

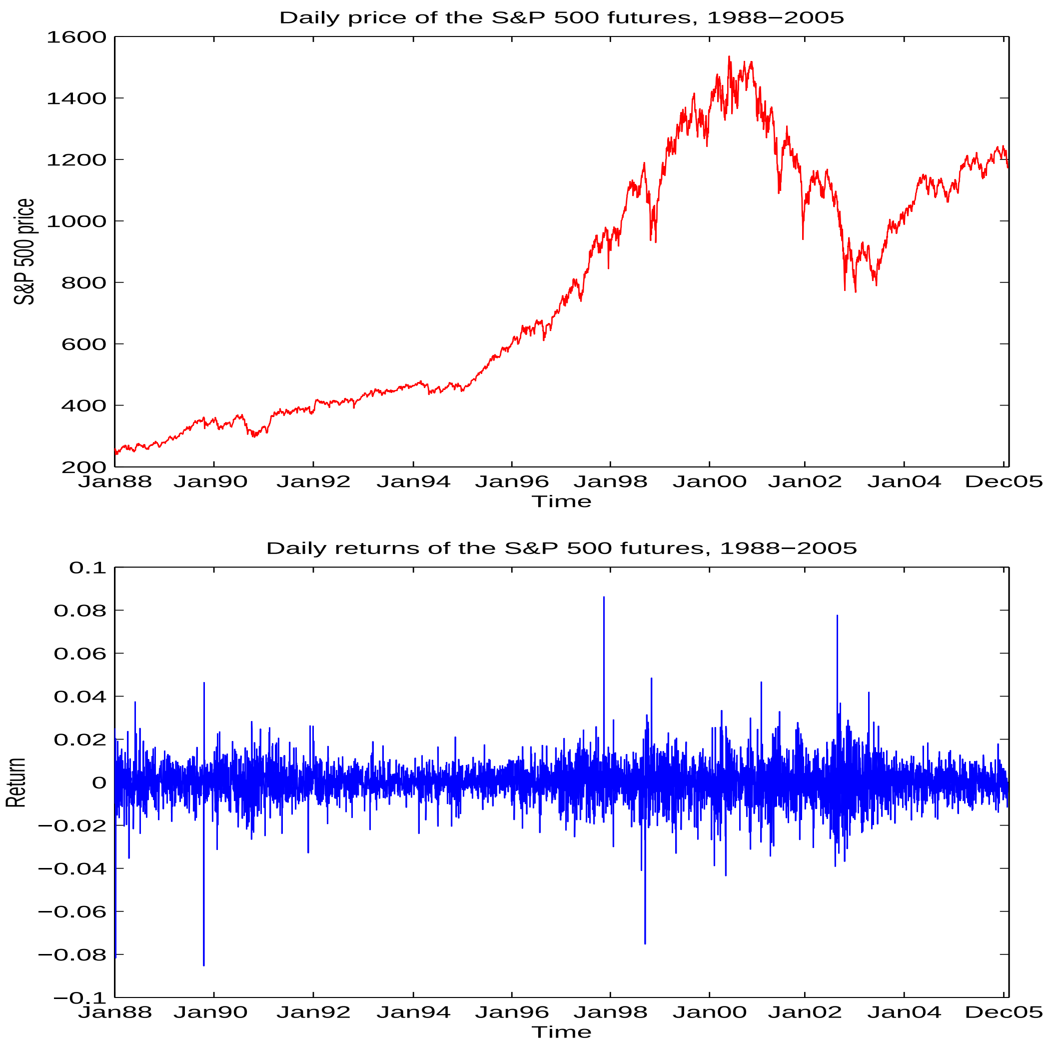


Figure 2. Daily realized volatility and bipower variation of the S&P 500 futures. January 1988 to December 2005.

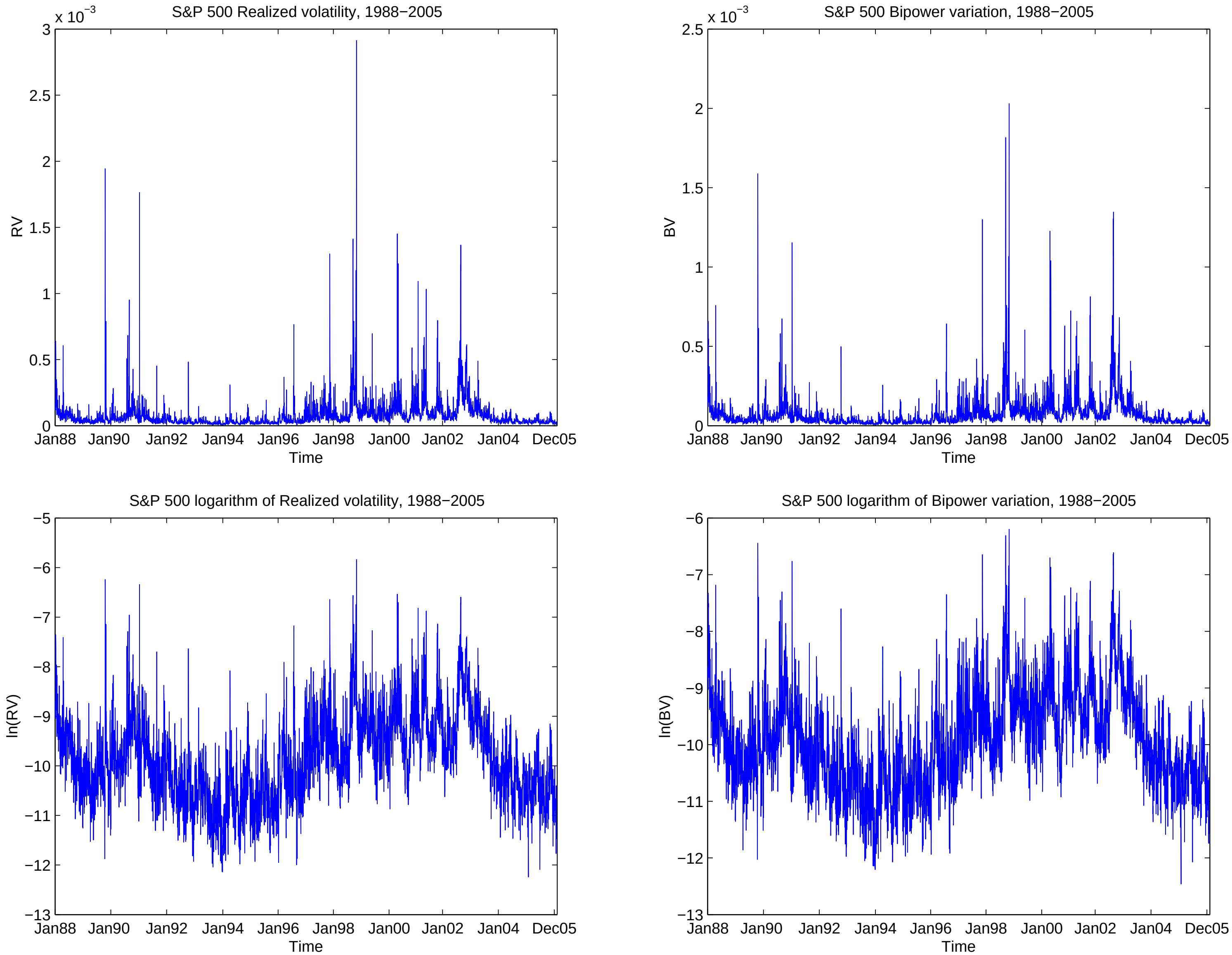
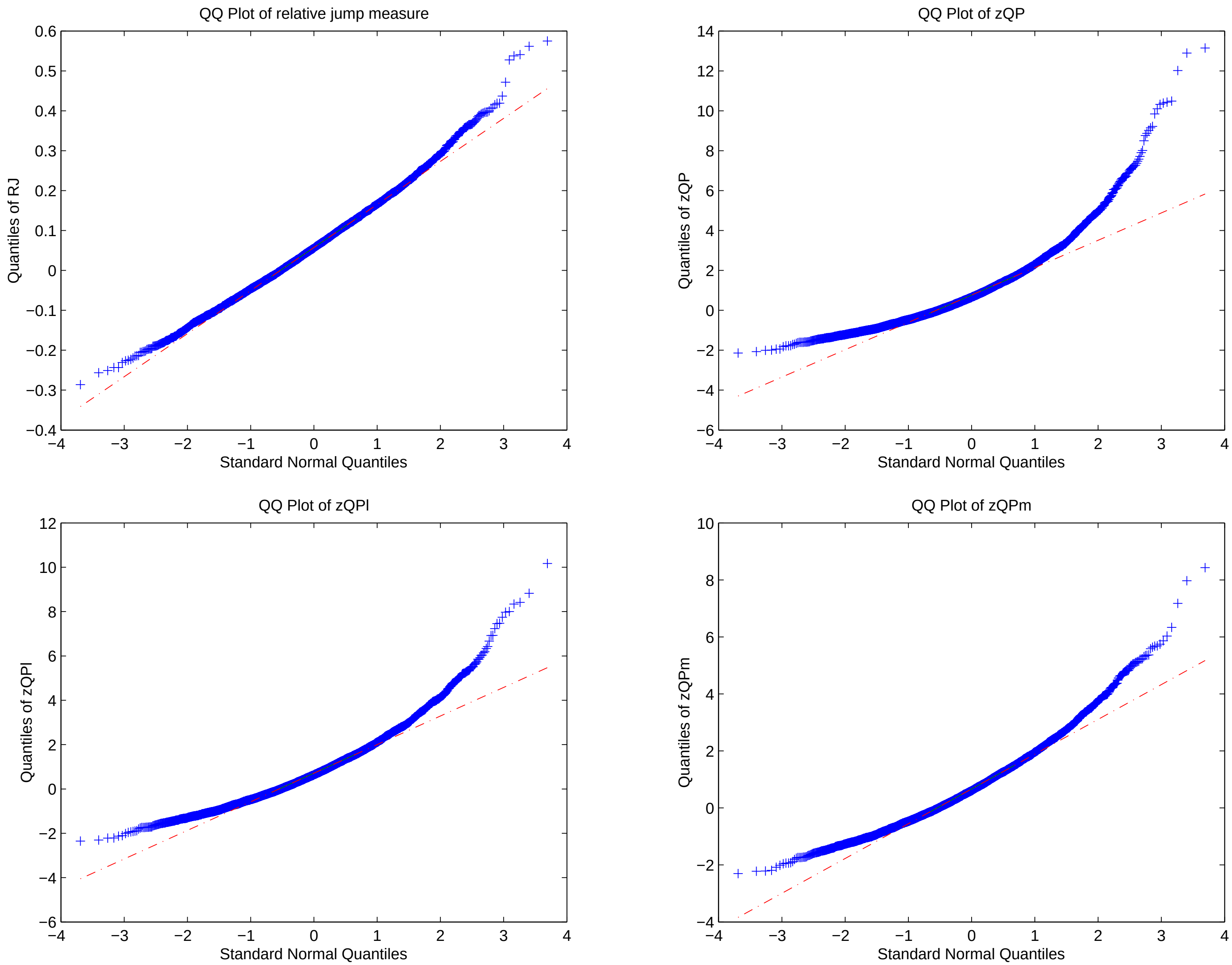


Figure 3. Quantile to quantile plots (QQ plot) of the relative measure of jumps (RJ), $z_{QP,l,t}$, $z_{QP,t}$, and $z_{QP,lm,t}$. January 1988 to December 2005.



3. Causality measures: summary results based on residual resampling bootstrap

In this section, Table 4 and Figure 4 present the results of hourly and daily volatility feedback and leverage effects and the comparison between them. Figure 5 compares the causality measures between daily implied volatility (IV) [or variance risk premium $IV - RV$] and daily realized volatility (RV), using trivariate VAR models for (r, RV, IV) and $(r, RV, IV - RV)$. Figures 6 and 7 provide the results of daily leverage and volatility feedback effects and the comparison between them in the presence of implied volatility [trivariate models (r, RV, IV) and $(r, RV, IV - RV)$] and in the absence of implied volatility [bivariate model (r, RV)]. Table 5 contains the parameter values used for the simulation study on the ability of the causality measures to detect asymmetry in the impact of bad and good return news on volatility [see Section 6.2 of the paper]. Figures 8 show the results of the simulation study on the ability of the causality measures to detect the differential effect of good and bad return news in various parametric volatility models. Finally, Tables 6-8 and Figures 9 and 10 contain the results of the impact of bad and good return and volatility news on volatility and returns using the data described in the previous section .

Table 4. Hourly and daily volatility feedback effects

Hourly volatility feedback effects using $\ln(RV)$

$C(\ln(RV) \underset{h}{\to} r)$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.00016	0.00014	0.00012	0.00012
95% Bootstrap interval	$[0.0000,\ 0.0007]$	$[0.0000,\ 0.0006]$	$[0.0000,\ 0.0005]$	$[0.0000,\ 0.0005]$

Hourly volatility feedback effects using $\ln(BV)$

$C(\ln(BV) \underset{h}{\to} r)$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.00022	0.00020	0.00019	0.00015
95% Bootstrap interval	$[0.0000,\ 0.0008]$	$[0.0000,\ 0.0007]$	$[0.0000,\ 0.0007]$	$[0.0000, 0.0005]$

Daily volatility feedback effects using $\ln(RV)$

$C(\ln(RV) \underset{h}{\to} r)$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0019	0.0019	0.0019	0.0011
95% Bootstrap interval	$[0.0007,\ 0.0068]$	$[0.0005,\ 0.0065]$	$[0.0004,\ 0.0061]$	$[0.0002,\ 0.0042]$

Daily volatility feedback effects using $\ln(BV)$

$C(\ln(BV) \underset{h}{\to} r)$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0017	0.0017	0.0016	0.0011
95% Bootstrap interval	$[0.0007,\ 0.0061]$	$[0.0005,\ 0.0056]$	$[0.0004,\ 0.0055]$	$[0.0002,\ 0.0042]$

Note: This table summarizes the estimation results of causality measures from hourly realized volatility $[\ln(RV)]$ to hourly returns (r), hourly bipower variation $[\ln(BV)]$ to hourly returns, daily realized volatility to daily returns, and daily bipower variation to daily returns, respectively. The second row in each small table gives the point estimate of the causality measures at horizons $h = 1, ..., 4$. The third row gives the 95% corresponding percentile bootstrap interval.

Table 5. Parameter values of different GARCH models

	ω	β	α	γ
GARCH	0.0000279	0.86695	0.093928	$-$
EGARCH	-0.290306	0.97000	0.093928	-0.09
NL-GARCH	0.0000279	0.86695	0.093928	$0.5,\ 1.5,\ 2.5$
GJR-GARCH	0.0000279	0.8805	0.032262	0.10542
AGARCH	0.0000279	0.86695	0.093928	-0.1108
VGARCH	0.0000279	0.86695	0.093928	-0.1108
NGARCH	0.0000279	0.86695	0.093928	-0.1108

Note: This table summarizes the parameter values for parametric volatility models considered in our simulations study.

Table 6. Measuring the impact of good return news on volatility using $\ln(RV)$ [centered positive returns]

$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{15}\sum_{j=1}^{15} r_{t+1-j}$

$C(er^{+} \underset{h}{\rightarrow} \ln(RV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0007	0.0007	0.0007	0.0004
95% Percentile bootstrap interval	$[0.0003, 0.0043]$	$[0.0002, 0.0039]$	$[0.0001, 0.0034]$	$[0.0000, 0.0030]$

$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{30}\sum_{j=1}^{30} r_{t+1-j}$

$C(er^{+} \underset{h}{\rightarrow} \ln(RV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0010	0.0007	0.0007	0.0005
95% Percentile bootstrap interval	$[0.0004, 0.0051]$	$[0.0003, 0.0039]$	$[0.0003, 0.0036]$	$[0.0000, 0.0032]$

$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{90}\sum_{j=1}^{90} r_{t+1-j}$

$C(er^{+} \underset{h}{\rightarrow} \ln(RV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0013	0.0008	0.0008	0.0008
95% Percentile bootstrap interval	$[0.0004, 0.0059]$	$[0.0003, 0.0044]$	$[0.0002, 0.0041]$	$[0.0001, 0.0039]$

$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{120}\sum_{j=1}^{120} r_{t+1-j}$

$C(er^{+} \underset{h}{\rightarrow} \ln(RV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0011	0.00076	0.00072	0.00074
95% Percentile bootstrap interval	$[0.0004, 0.0054]$	$[0.00029, 0.0041]$	$[0.00024, 0.00386]$	$[0.0000, 0.00388]$

$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{240}\sum_{j=1}^{240} r_{t+1-j}$

$C(er^{+} \underset{h}{\rightarrow} \ln(RV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0011	0.0006	0.0006	0.0007
95% Percentile bootstrap interval	$[0.0004, 0.0053]$	$[0.0003, 0.0041]$	$[0.0002, 0.0035]$	$[0.0000, 0.0034]$

Note: This table summarizes the estimation results of causality measures from centered positive returns (er^{+}) to realized volatility $[\ln(RV)]$ using five estimators of the conditional mean, for $m = 15,\ 30,\ 90,\ 120,\ 240$. In each of the five small tables, the second row gives the point estimate of the causality measures at horizons $h = 1, ..., 4$. The third row gives the 95% corresponding percentile bootstrap interval.

Table 7. Measuring the impact of good return news on volatility using $\ln(BV)$ [centered positive returns]

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{15}\sum_{j=1}^{15} r_{t+1-j}$$

$C(er^+ \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0008	0.0008	0.0006	0.0006
95% Percentile bootstrap interval	$[0.0003, 0.0045]$	$[0.0002, 0.0041]$	$[0.0002, 0.0035]$	$[0.0000, 0.0034]$

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{30}\sum_{j=1}^{30} r_{t+1-j}$$

$C(er^+ \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0012	0.0007	0.0007	0.0007
95% Percentile bootstrap interval	$[0.0005, 0.0053]$	$[0.0003, 0.0041]$	$[0.0002, 0.0039]$	$[0.0001, 0.0038]$

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{90}\sum_{j=1}^{90} r_{t+1-j}$$

$C(er^+ \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0018	0.0009	0.0008	0.0010
95% Percentile bootstrap interval	$[0.0006, 0.0065]$	$[0.0003, 0.0044]$	$[0.0002, 0.0041]$	$[0.0001, 0.0042]$

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{120}\sum_{j=1}^{120} r_{t+1-j}$$

$C(er^+ \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0016	0.0008	0.0007	0.0009
95% Percentile bootstrap interval	$[0.0006, 0.0063]$	$[0.0002, 0.0047]$	$[0.0002, 0.0042]$	$[0.0001, 0.0044]$

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{240}\sum_{j=1}^{240} r_{t+1-j}$$

$C(er^+ \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0015	0.0007	0.0006	0.0008
95% Percentile bootstrap interval	$[0.0005, 0.0057]$	$[0.0002, 0.0044]$	$[0.0002, 0.0038]$	$[0.0001, 0.0037]$

Note: This table summarizes the estimation results of causality measures from centered positive returns (er^+) to bipower variation [$\ln(BV)$] using five estimators of the conditional mean, for $m = 15,\ 30,\ 90,\ 120,\ 240$. In each of the five small tables, the second row gives the point estimate of the causality measures at horizons $h = 1, ..., 4$. The third row gives the 95% corresponding percentile bootstrap interval.

Table 8. Measuring the impact of good return news on volatility [uncentered positive returns]

using $\ln(RV)$

$C(r^{+} \underset{h}{\to} \ln(RV))$	$h = 1$	$h = 2$	$h = 3$	$h = 4$
Point estimate	0.0027	0.0012	0.0008	0.0009
95% Percentile bootstrap interval	$[0.0011,\ 0.0077]$	$[0.0004,\ 0.0048]$	$[0.0002,\ 0.0041]$	$[0.0001,\ 0.0038]$

using $\ln(BV)$

$C(r^{+} \underset{h}{\to} \ln(BV))$	$h = 1$	$h = 2$	$h = 3$	$h = 4$
Point estimate	0.0035	0.0013	0.0008	0.0010
95% Percentile bootstrap interval	$[0.0016,\ 0.0087]$	$[0.0004,\ 0.0051]$	$[0.0002,\ 0.0039]$	$[0.0001, 0.0043]$

Note: This table summarizes the estimation results of causality measures from uncentered positive returns (r^{+}) to realized volatility $[\ln(RV)]$ [bipower variation $\ln(BV)$]. The second row of each small table gives the point estimate of the causality measures at horizons $h = 1, \ldots, 4$. The third row gives the 95% corresponding percentile bootstrap interval.

Figure 4. Leverage and volatility feedback effects in hourly and daily data using a bivariate autoregressive model (r, RV). January 1988 to December 2005.

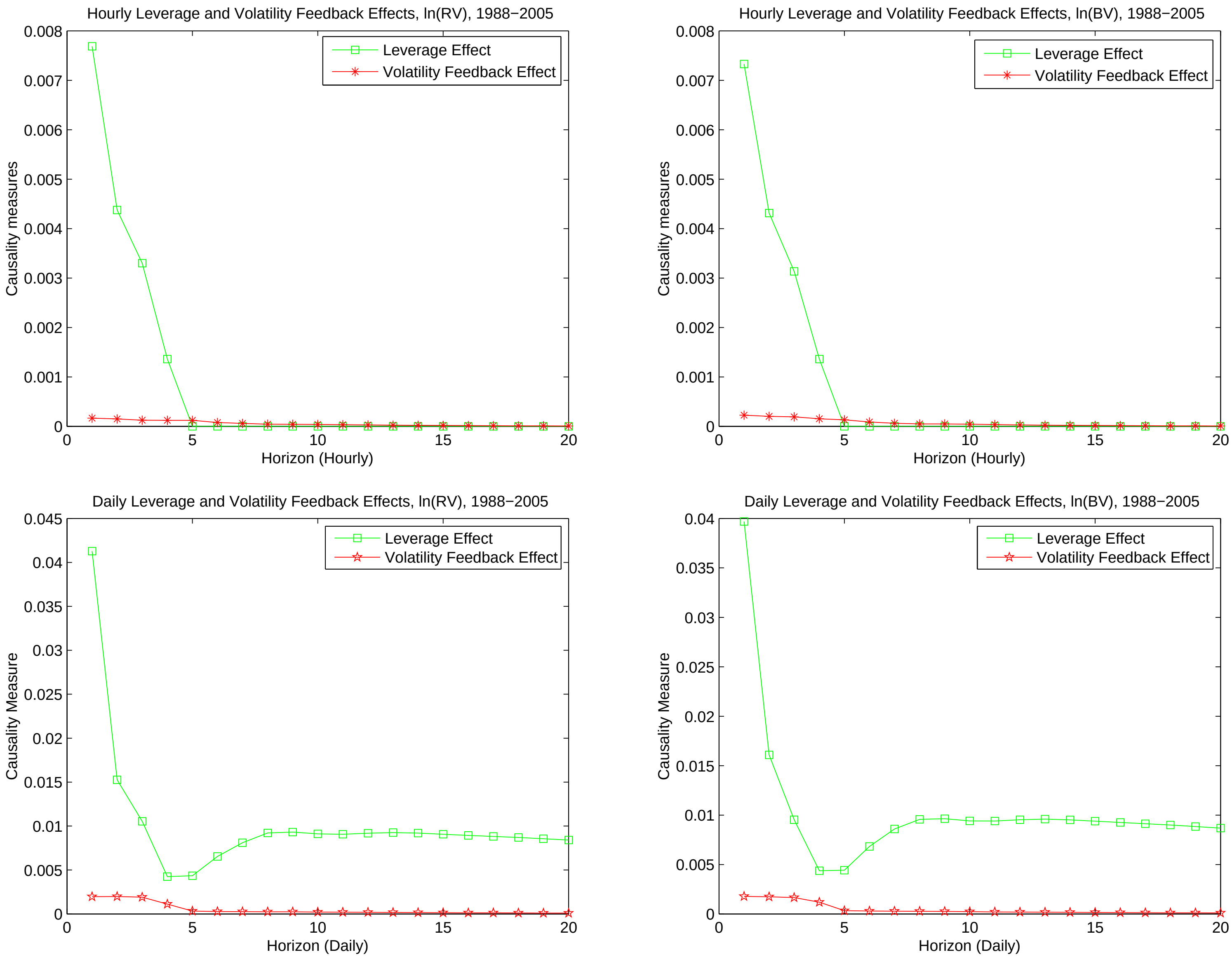


Figure 5. Causality measures between implied volatility (IV) [or variance risk premium $IV - RV$] and realized volatility (RV), using trivariate VAR models for (r, RV, IV) and $(r, RV, IV - RV)$. January 1996 to December 2005.

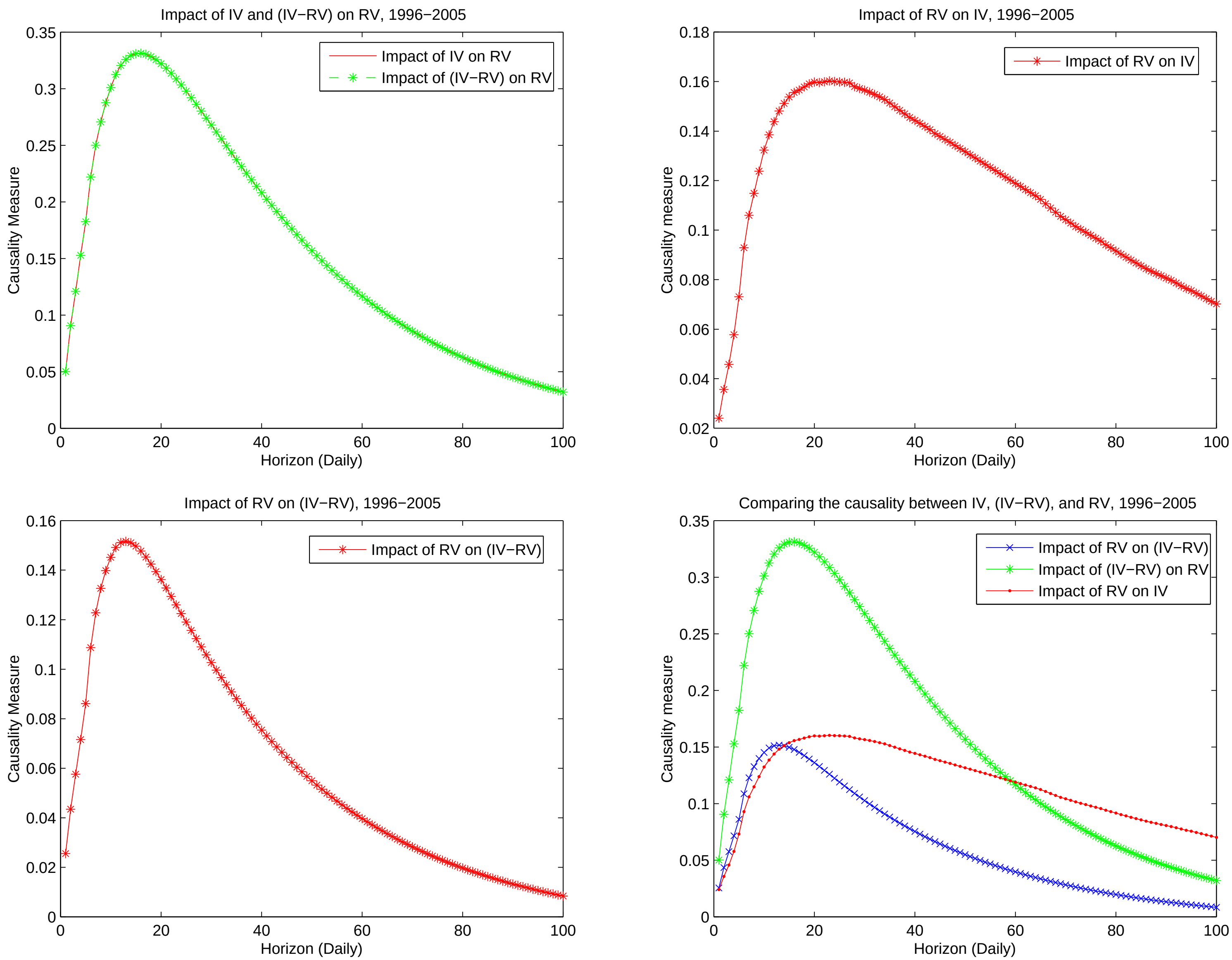


Figure 6. Volatility feedback effects, with implied volatility as auxiliary variable [trivariate models (r, RV, IV) and $(r, RV, IV - RV)$] and without implied volatility [bivariate model (r, RV)]; different transformations of volatility considered. Impact of vector $(RV,\ IV - RV)$ on returns. January 1996 to December 2005.

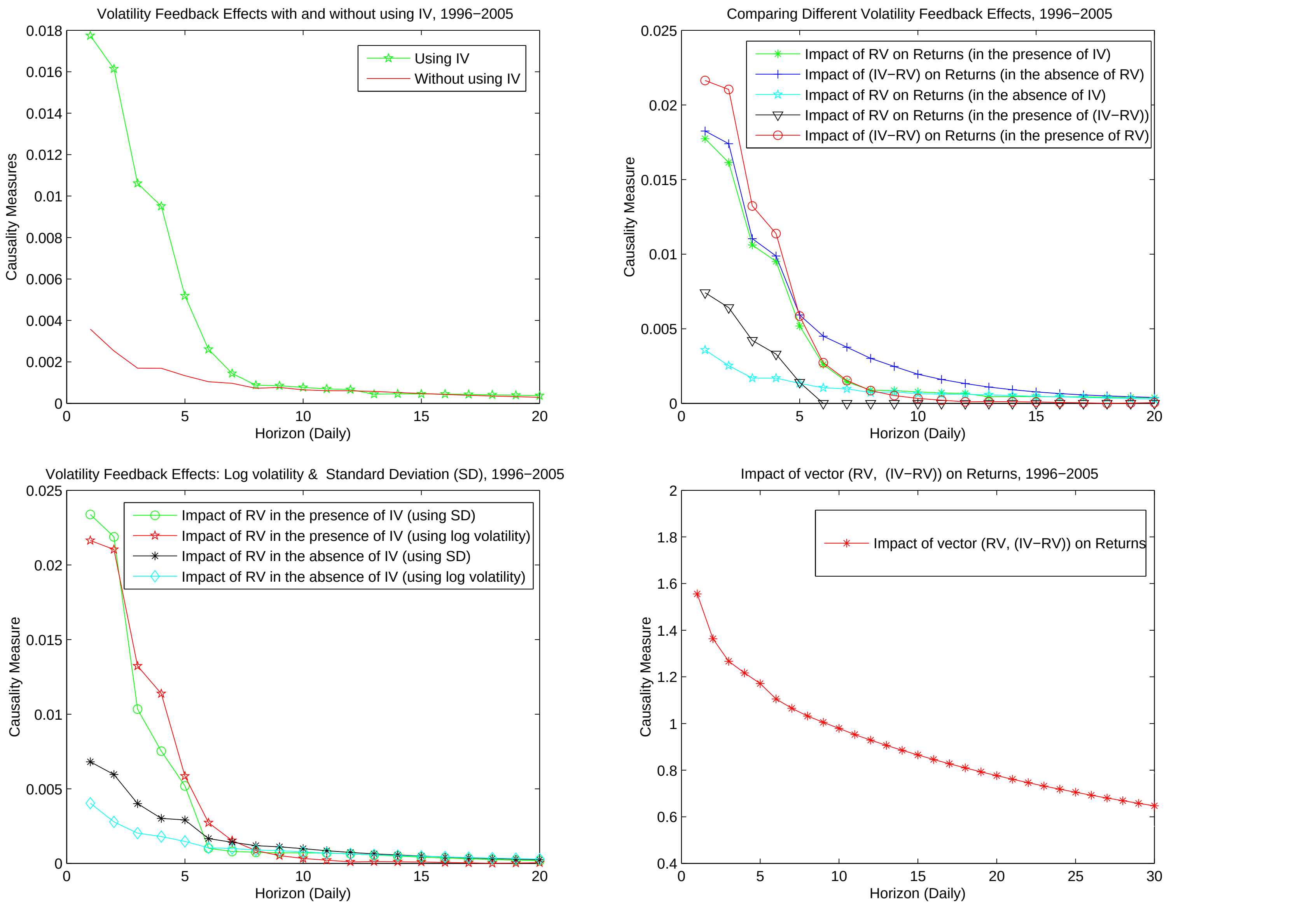


Figure 7. Leverage and volatility feedback effects, with implied volatility as auxiliary variable [trivariate models (r, RV, IV) and $(r, RV, IV - RV)$] and without implied volatility [bivariate model (r, RV)]. January 1996 to December 2005.

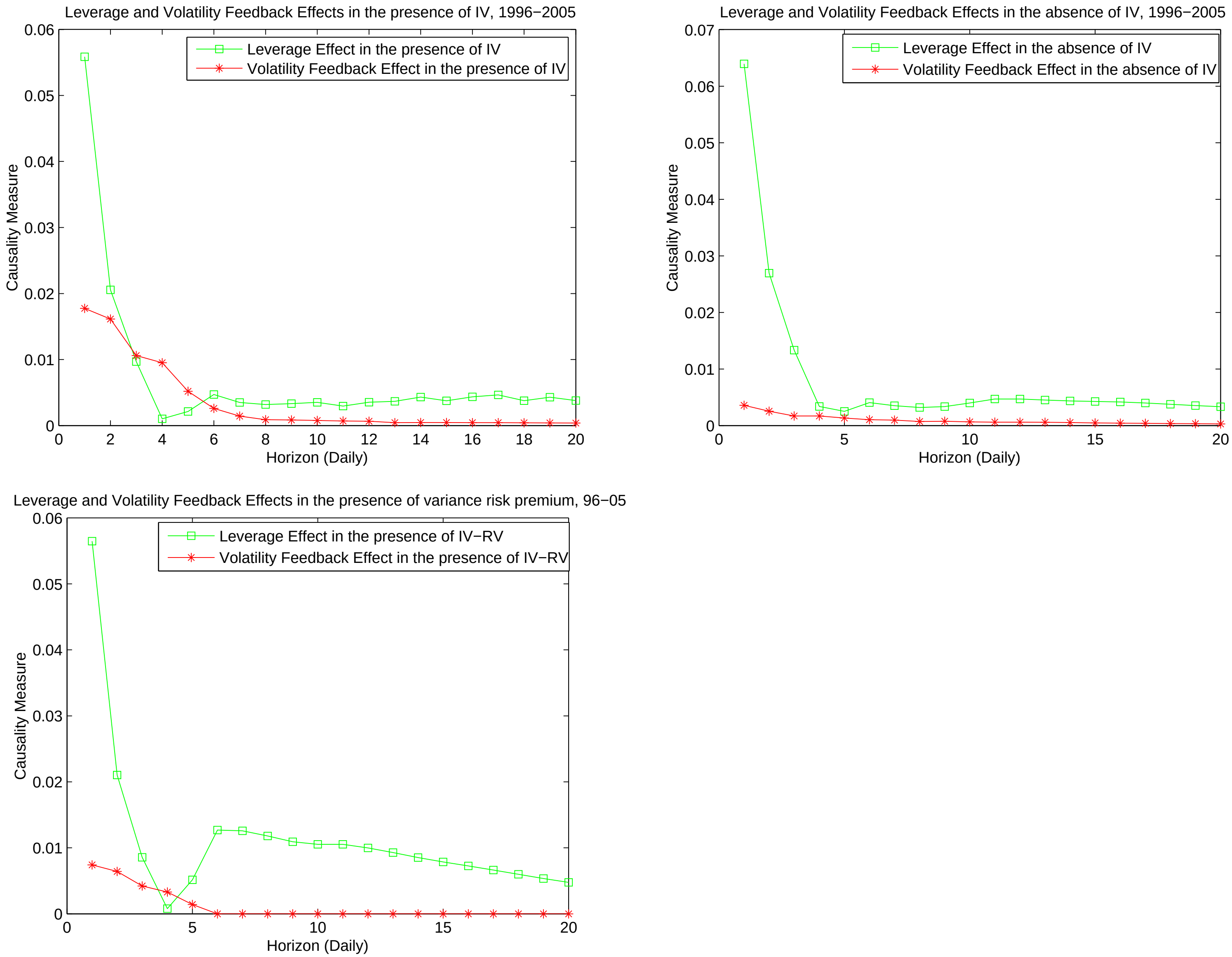


Figure 8. Causality measures of the impact of bad and good return news on symmetric and asymmetric GARCH volatility models.

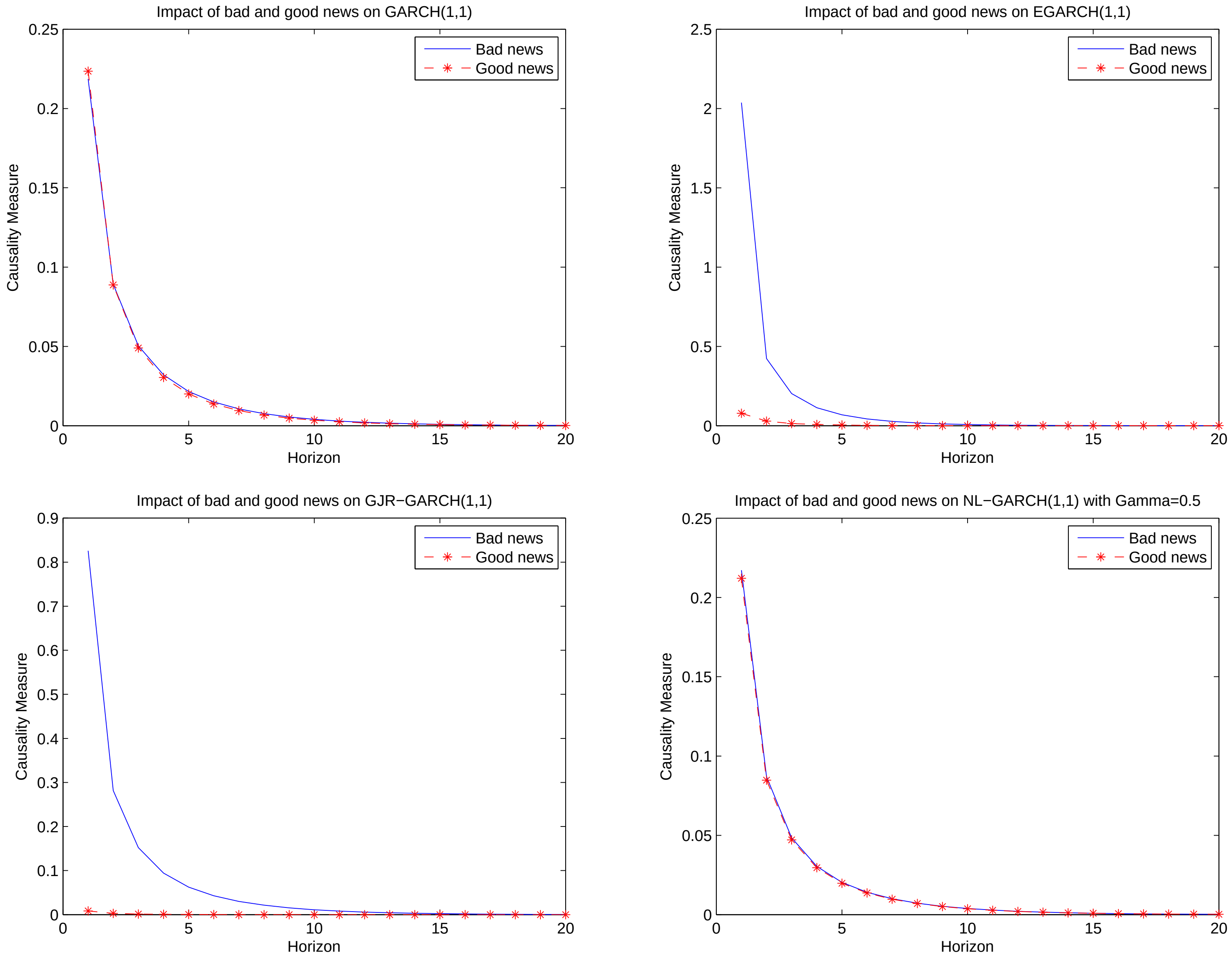


Figure 8 (continued). Causality measures of the impact of bad and good return news on symmetric and asymmetric GARCH volatility models.

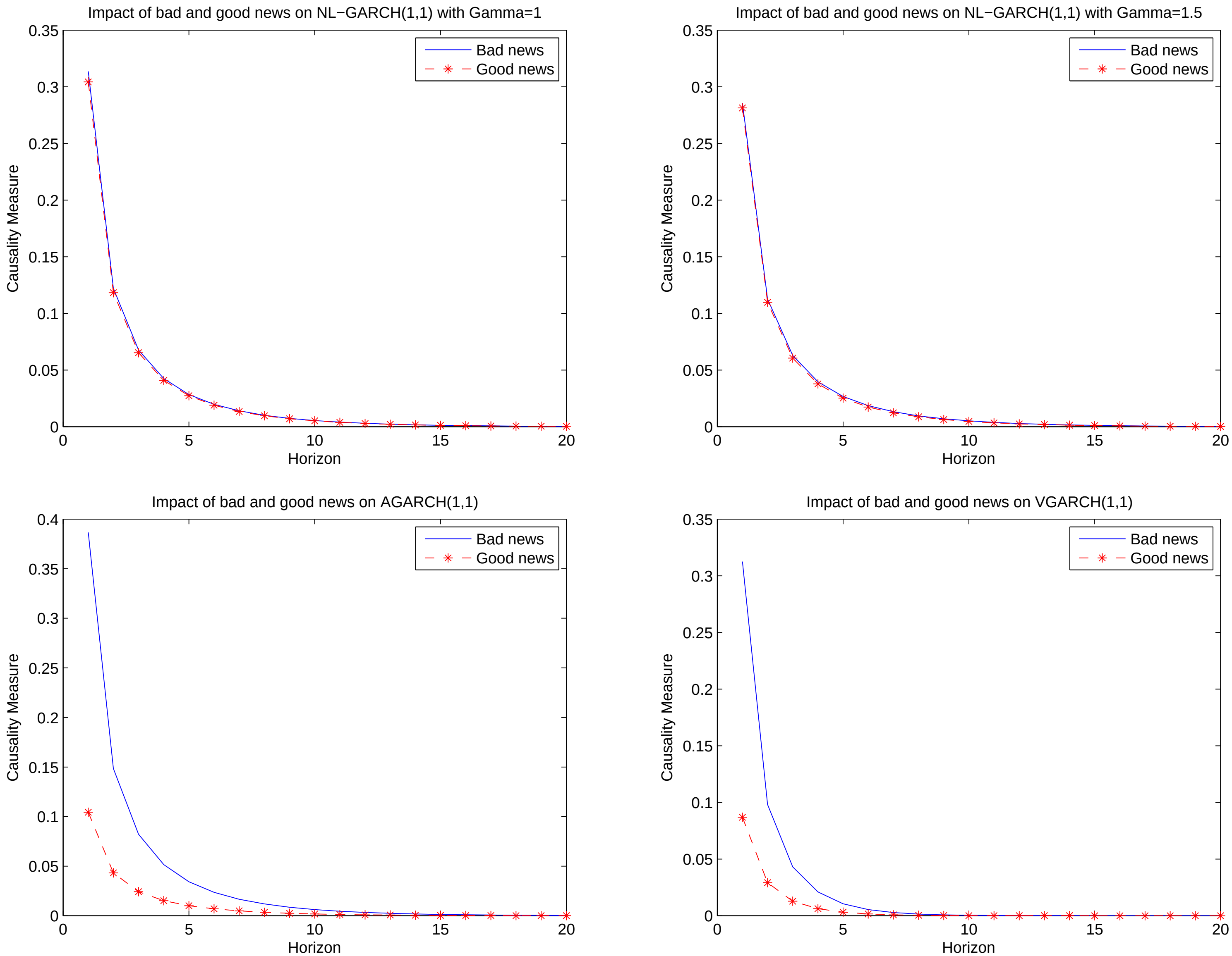


Figure 8 (continued). Causality measures of the impact of bad and good return news on symmetric and asymmetric GARCH volatility models.

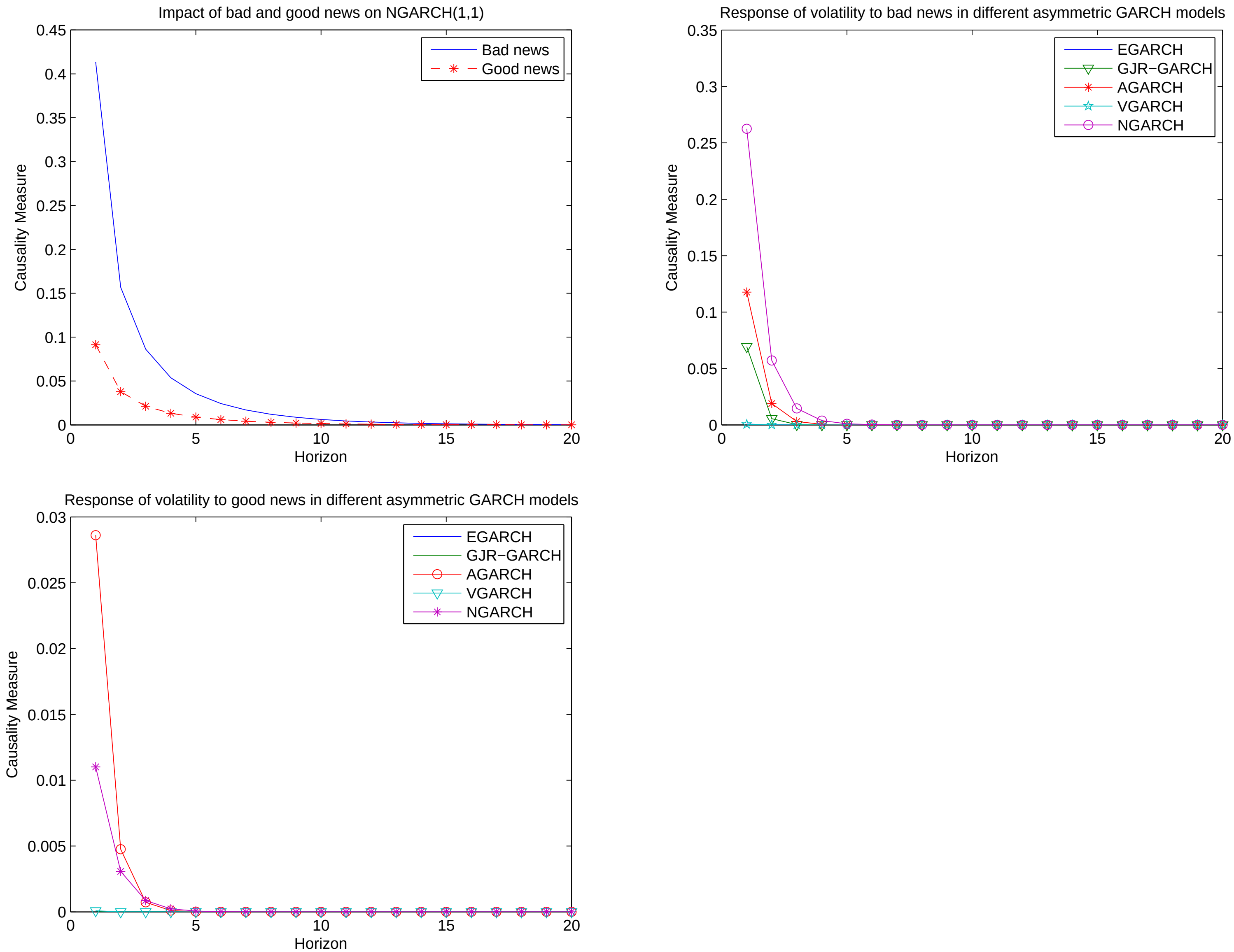


Figure 9. Causality measures of the impact of bad and good return news on volatility, based on realized volatility $[\ln(RV)]$ and bipower variation $[\ln(BV)]$. January 1988 to December 2005.

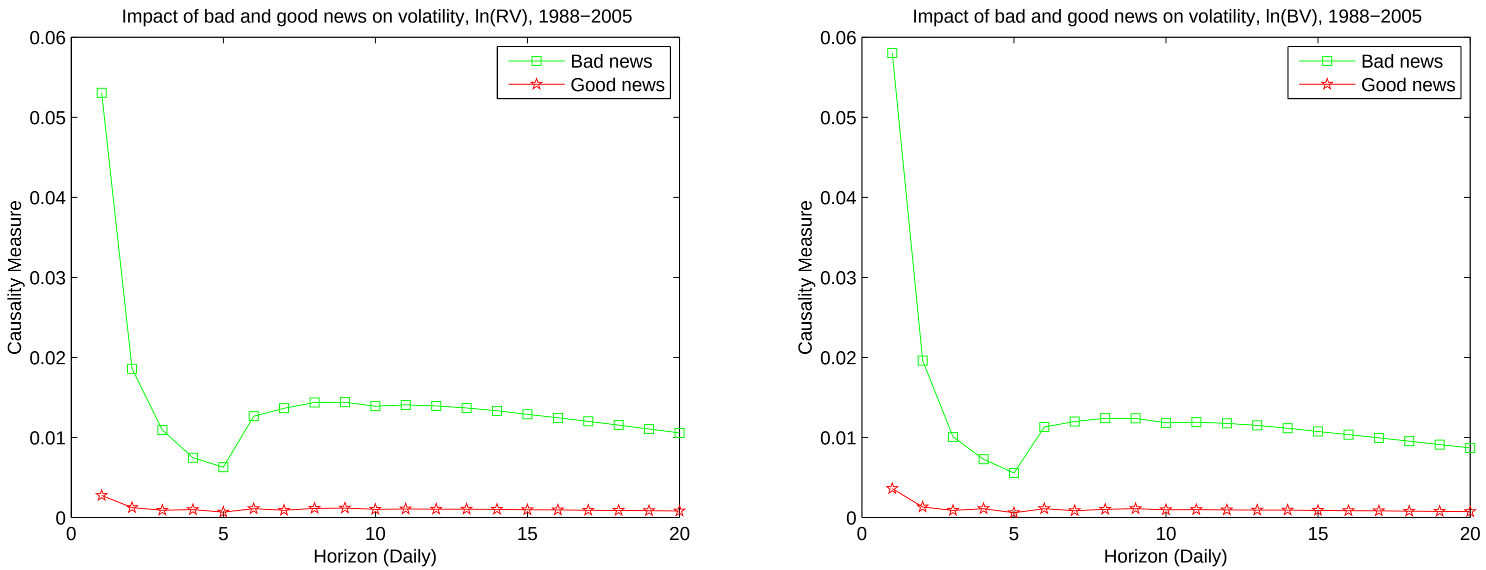
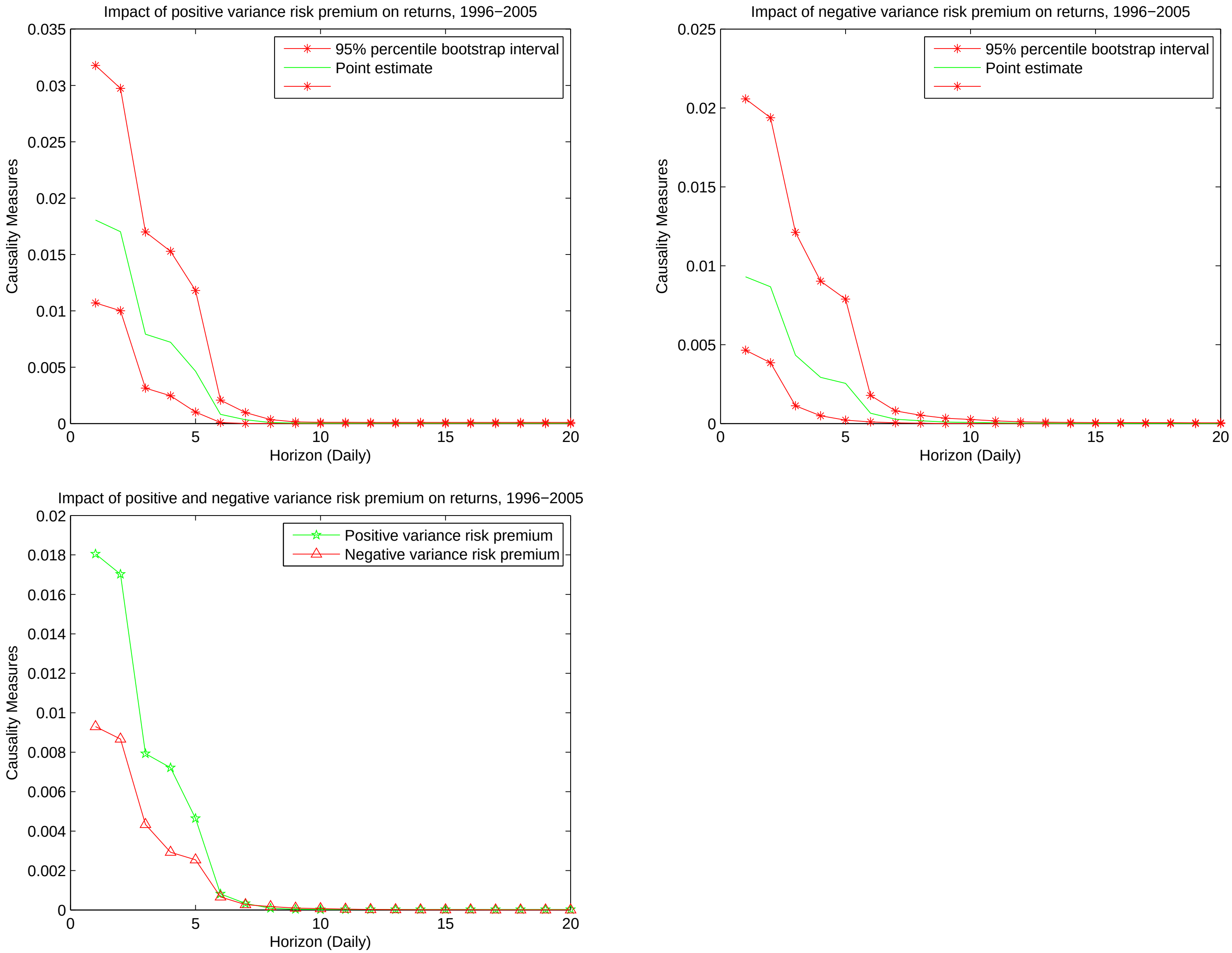


Figure 10. Causality measures of the impact of positive and negative variance risk premium on returns. January 1996 to December 2005.



4. Causality measures: results based on residual resampling bootstrap

In this section, we provide point estimates and confidence intervals (with level 0.95) for causality measures based on the residual resampling bootstrap method described in Dufour et al. (2010). The relationships considered include:

1. Figure 11: leverage effect in hourly and daily data, using bivariate models for $(r, \ln(RV))$ and $(r, \ln(BV))$;

2. Figure 12: instantaneous causality and dependence between daily returns and volatility using bivariate models for $(r, \ln(RV))$ and $(r, \ln(BV))$;

3. Figure 13: measures of causality between daily implied volatility (IV) [or the variance risk premium $IV - RV$] and realized volatility (RV), using trivariate VAR models for (r, RV, IV) and $(r, RV, IV - RV)$;

4. Figure 14: volatility feedback effects, with implied volatility as auxiliary variable [trivariate model $(r,\ RV,\ IV)$] and without implied volatility [bivariate model $(r,\ RV)$];

5. Figure 15: volatility feedback effects using variance risk premium $(IV - RV)$, and the impact of $(RV,\ IV - RV)$ on returns (daily data);

6. Figure 16: leverage effects (in daily data), with implied volatility as an auxiliary variable [trivariate model $(r,\ RV,\ IV)$ or $(r,\ RV,\ IV - RV)$] and without implied volatility [bivariate model $(r,\ RV)$];

7. Figure 17: the impact of bad return news on volatility (in daily data), using 5 estimators of the conditional mean return $(m = 15,\ 30,\ 90,\ 120,\ 240)$, realized volatility $[\ln(RV)]$ and bipower variation $[\ln(BV)]$.

Figure 11. Leverage effects in hourly and daily data, using bivariate models for $(r,\ \ln(RV))$ and $(r,\ \ln(BV))$. January 1988 to December 2005.

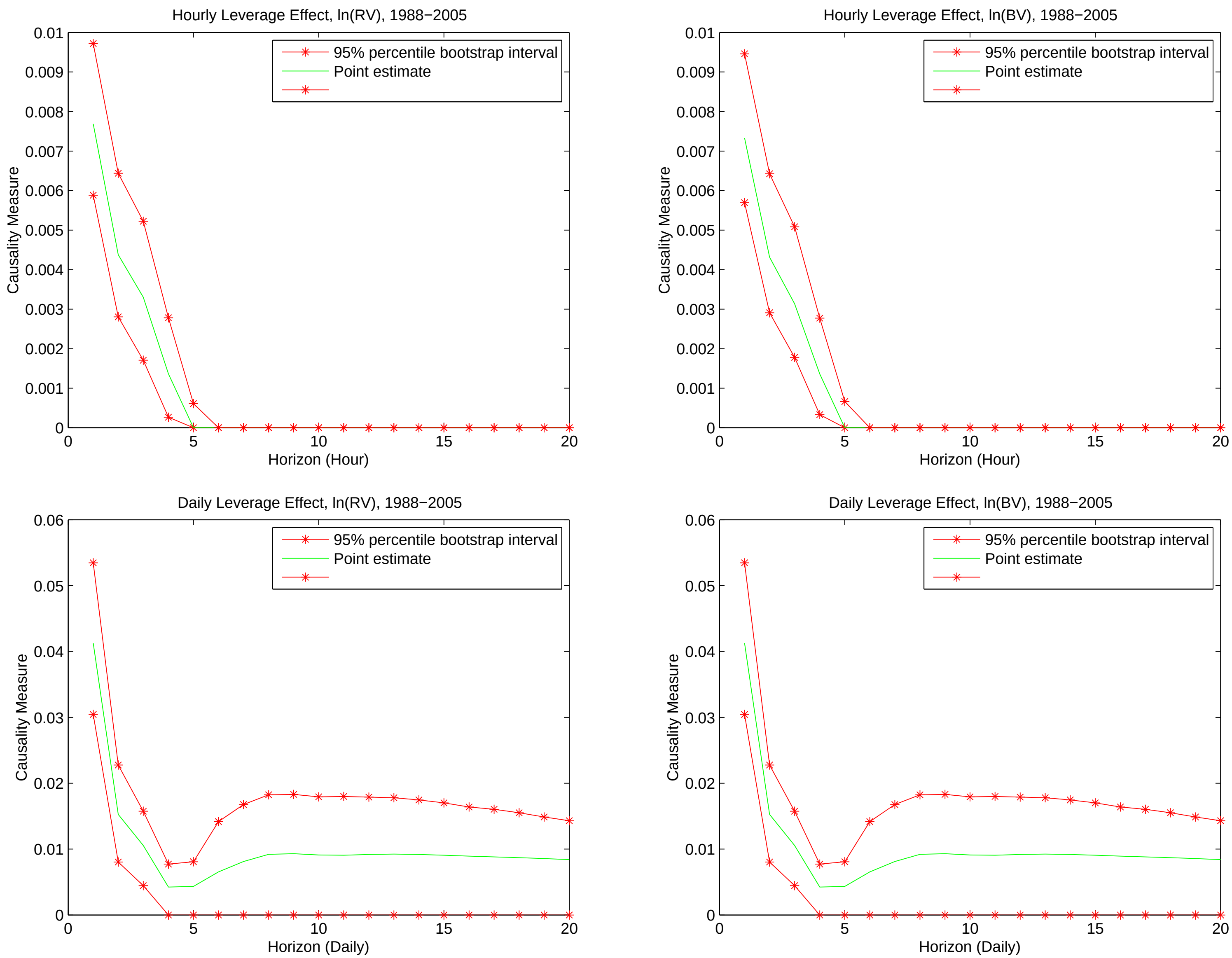


Figure 12. Instantaneous causality and dependence between daily returns and volatility using bivariate models for $(r, \ln(RV))$ and $(r, \ln(BV))$. January 1988 to December 2005.

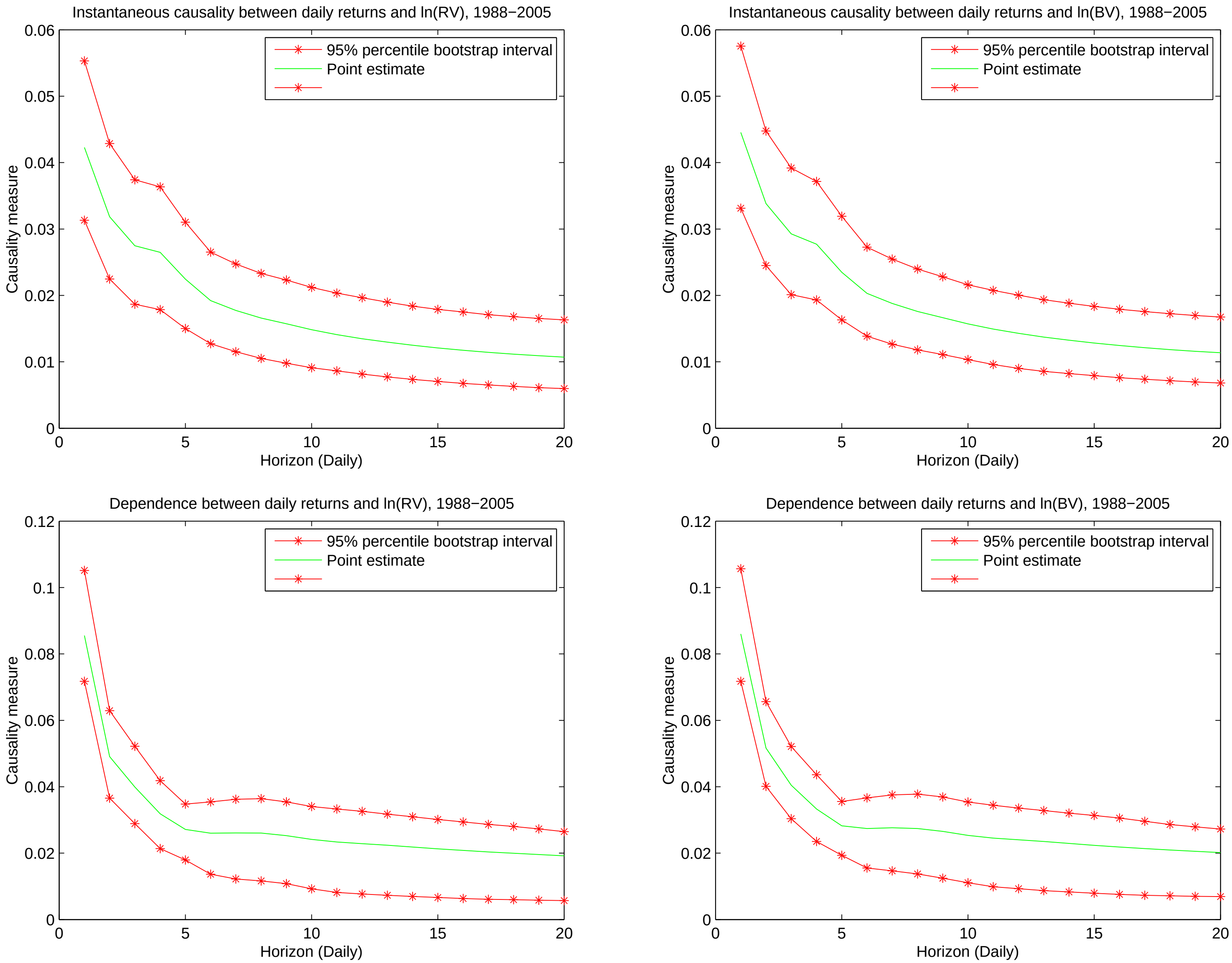


Figure 13. Causality measures between implied volatility (IV) [or variance risk premium $IV - RV$] and realized volatility (RV), using trivariate VAR models for (r, RV, IV) and $(r, RV, IV - RV)$. January 1996 to December 2005.

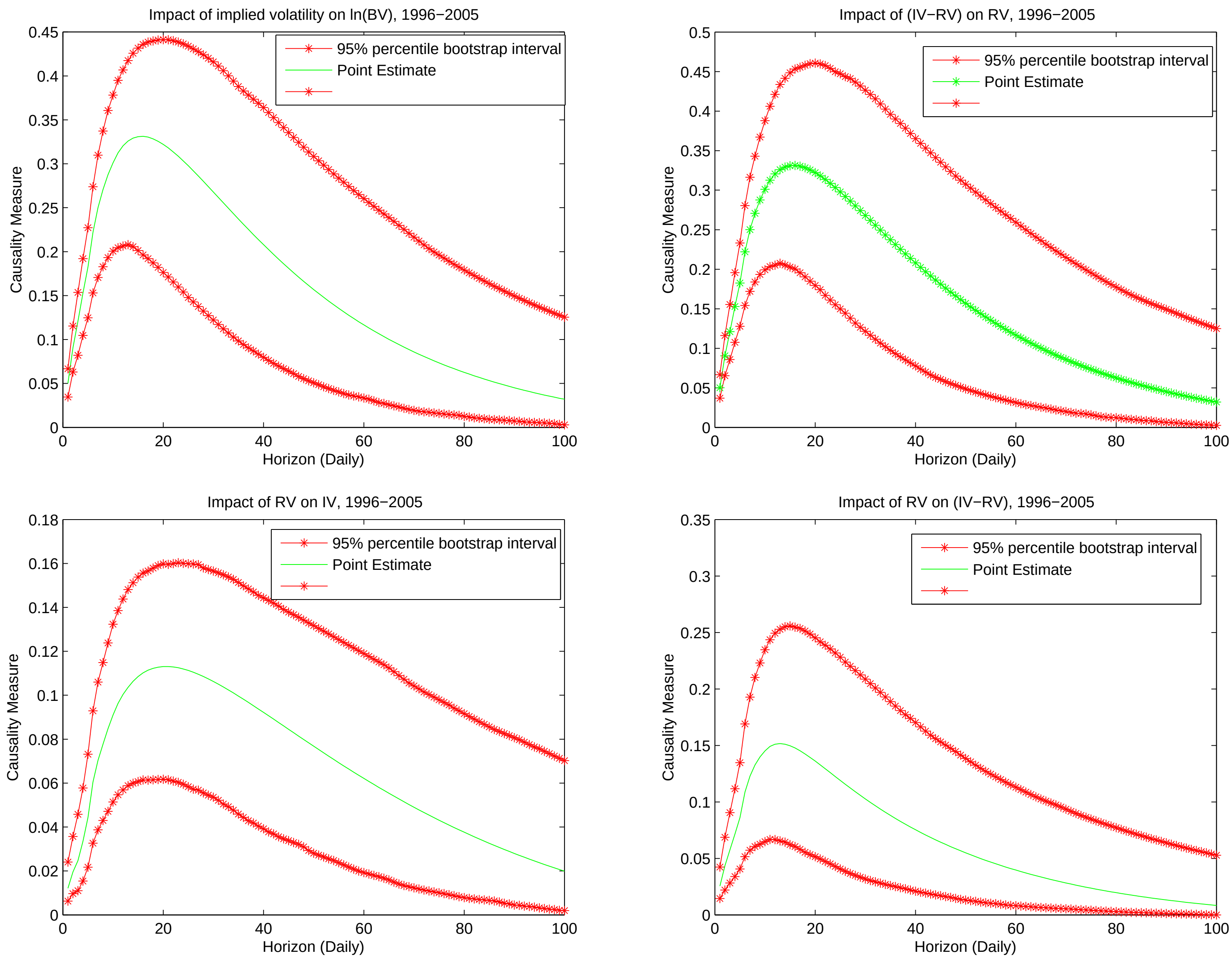


Figure 14. Volatility feedback effects, with implied volatility as auxiliary variable [trivariate model $(r,\ RV,\ IV)$] and without implied volatility [bivariate model $(r,\ RV)$]. January 1996 to December 2005.

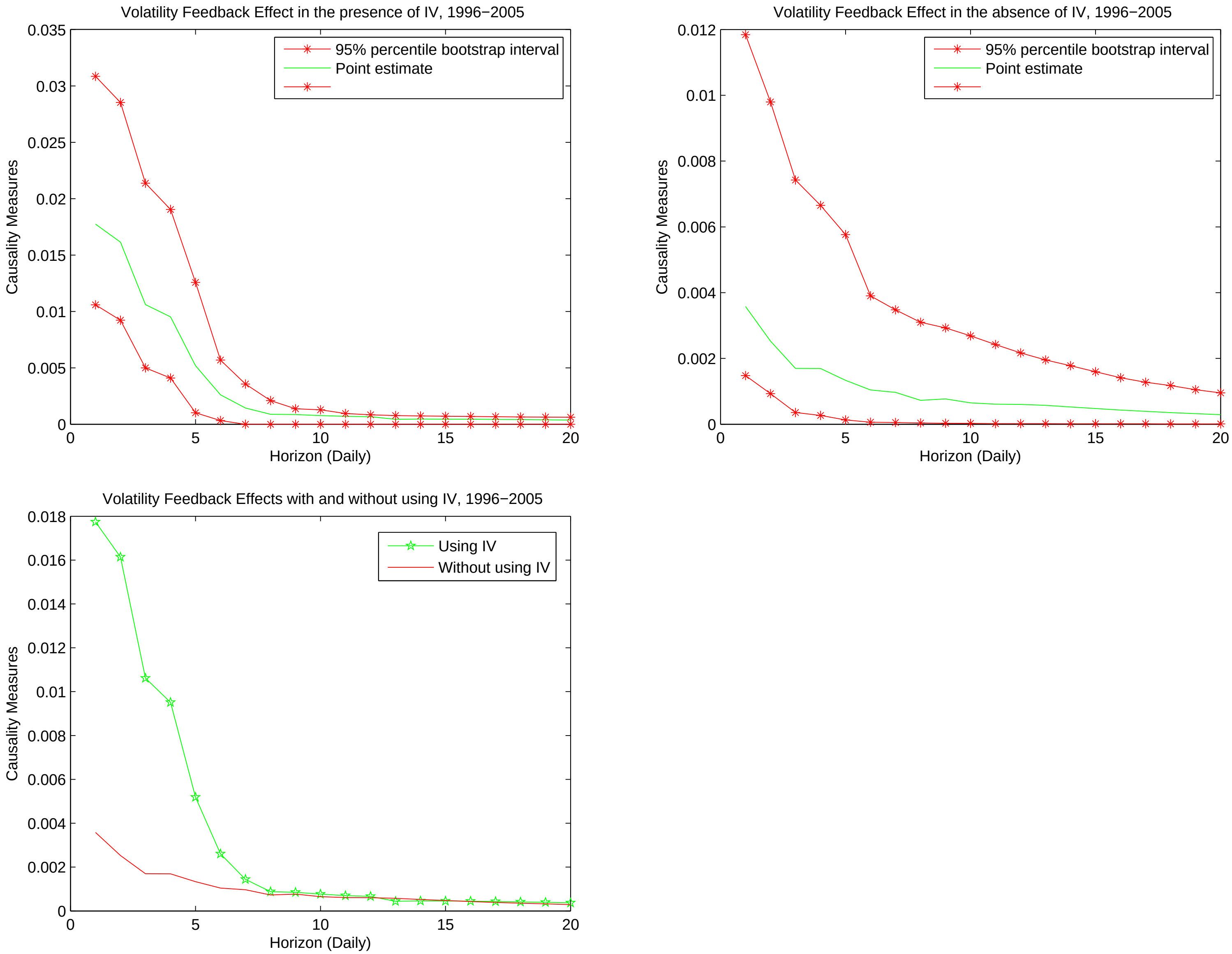


Figure 15. Other volatility feedback effects using variance risk premium $(IV - RV)$ and impact of $(RV, IV - RV)$ on returns. January 1996 to December 2005.

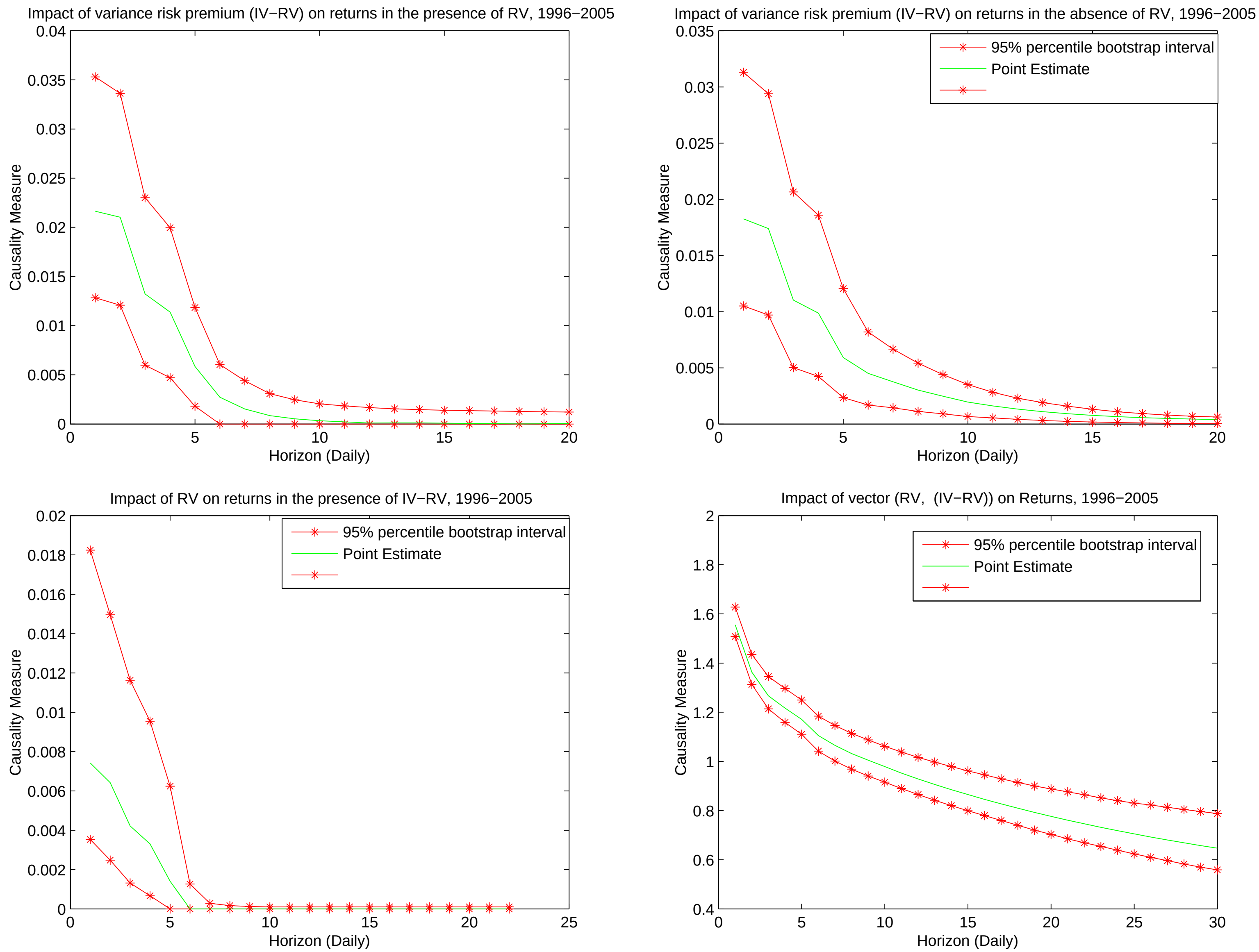


Figure 16. Leverage effects, with implied volatility as auxiliary variable [trivariate model $(r,\ RV,\ IV)$ or $(r,\ RV,\ IV - RV)$] and without implied volatility [bivariate model $(r,\ RV)$]. January 1996 to December 2005.

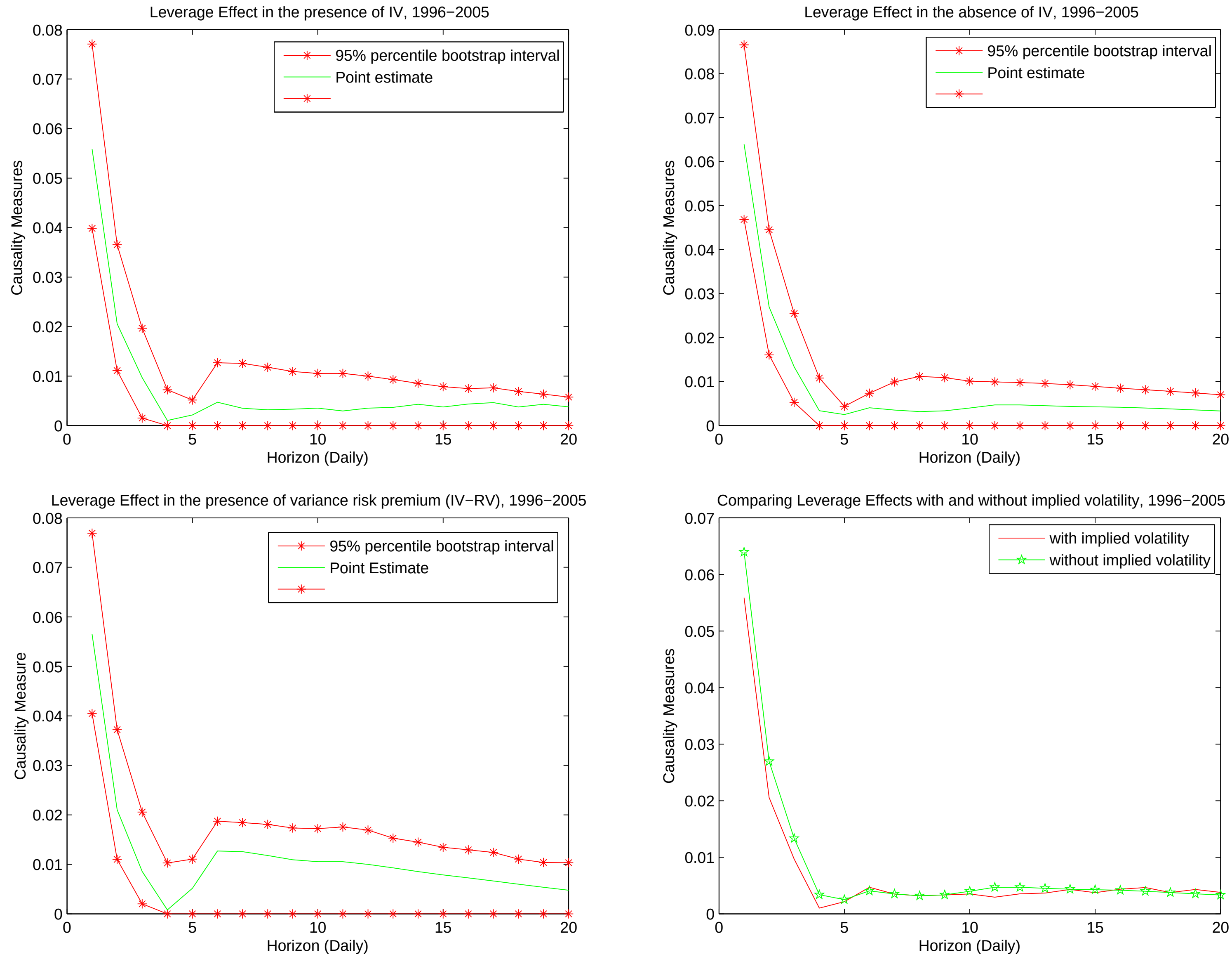


Figure 17. Causality measures of the impact of bad return news on volatility, using 5 estimators of the conditional mean return ($m = 15, 30, 90, 120, 240$), realized volatility $[\ln(RV)]$ and bipower variation $[\ln(BV)]$. January 1988 to December 2005.

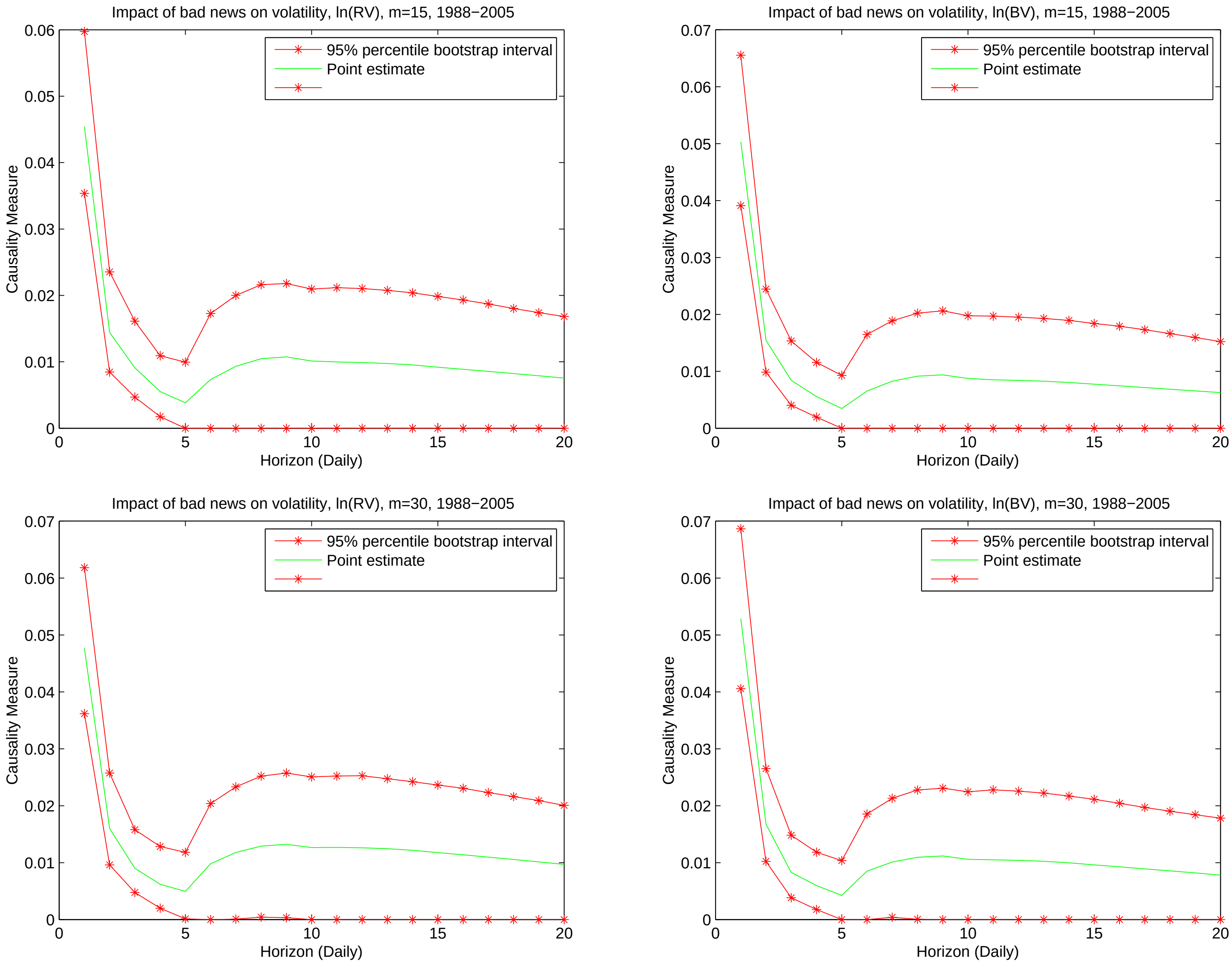


Figure 17 (continued). Causality measures of the impact of bad return news on volatility, using 5 estimators of the conditional mean return $(m = 15, 30, 90, 120, 240)$, realized volatility $[\ln(RV)]$ and bipower variation $[\ln(BV)]$. January 1988 to December 2005.

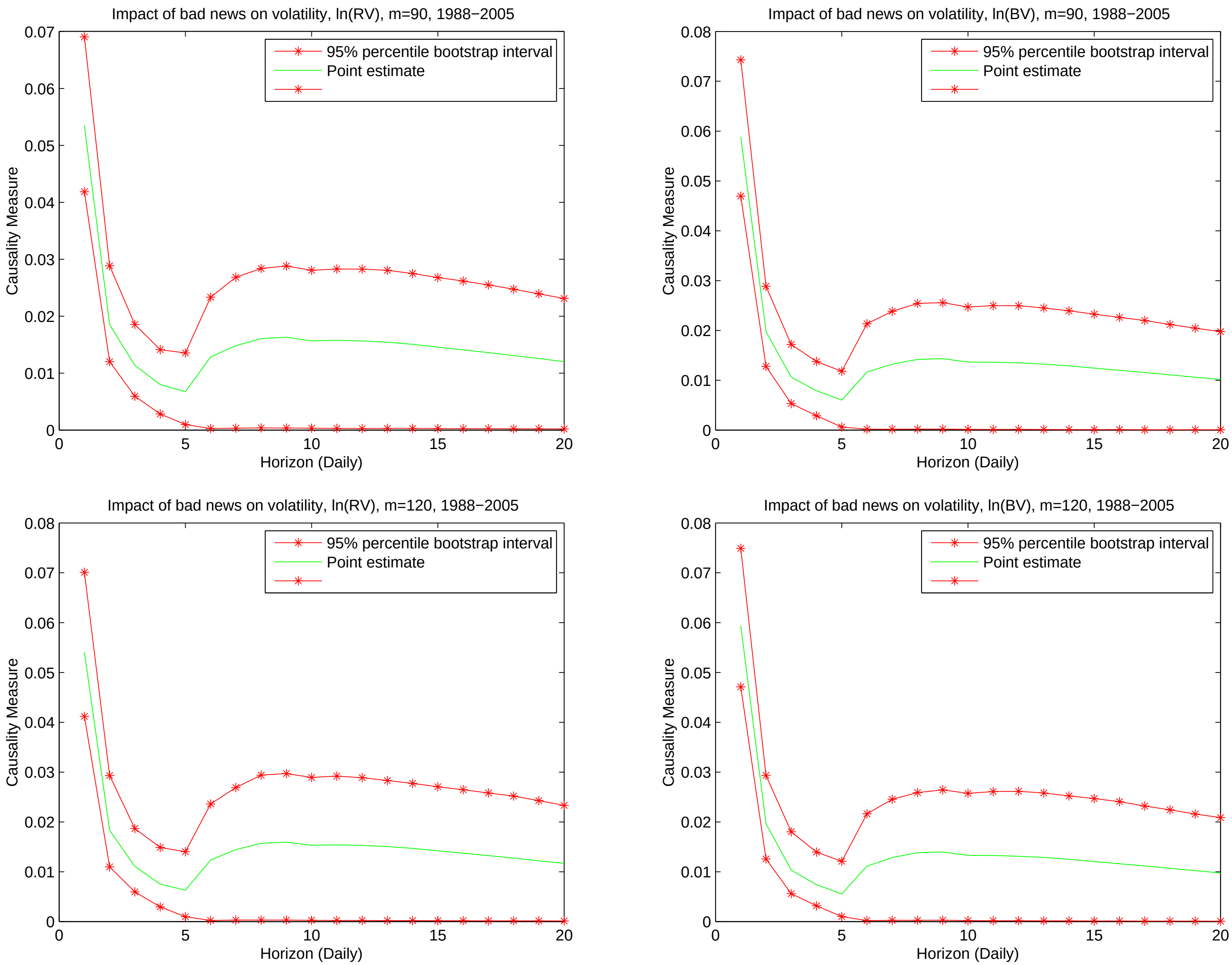
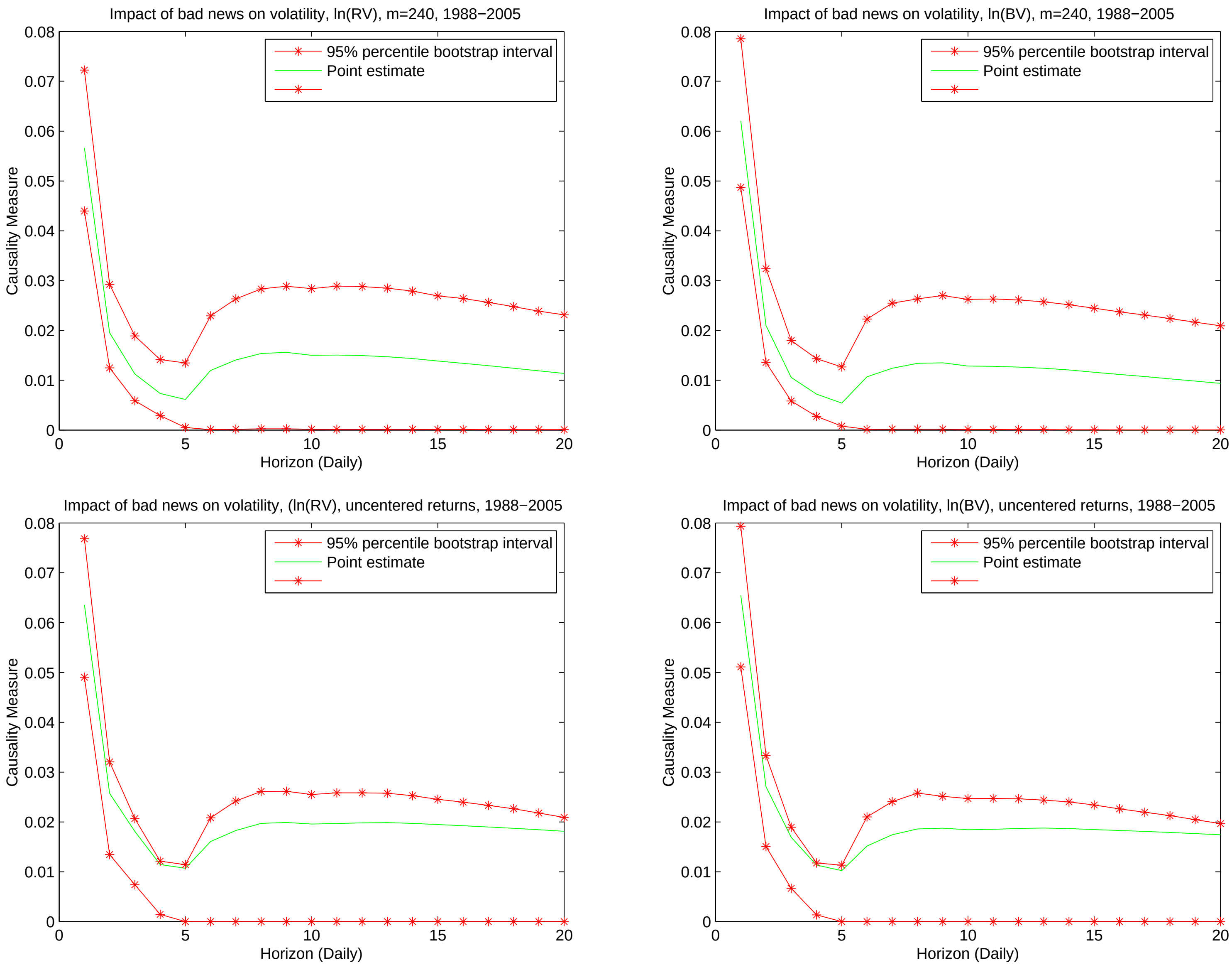


Figure 17 (continued). Causality measures of the impact of bad return news on volatility, using 5 estimators of the conditional mean return $(m = 15, 30, 90, 120, 240)$, realized volatility $[\ln(RV)]$ and bipower variation $[\ln(BV)]$. January 1988 to December 2005.



5. Causality measures: results based on fixed-design wild bootstrap

In this section, we provide point estimates and confidence intervals (with level 0.95) for causality measures based on a fixed-design wild bootstrap as described by Gonçalves and Kilian (2004). The relationships analyzed include:

1. Table 9: hourly and daily volatility feedback effects using bivariate models, realized volatility and bipower variation;

2. Table 10: causality measures of the impact of good return news on volatility using 5 estimators of the conditional mean return and realized volatility;

3. Table 11: causality measures of the impact of good return news on volatility, using 5 estimators of the conditional mean return and bipower variation;

4. Table 12: causality measures of the impact of good return news on volatility using uncentered positive returns, realized volatility and bipower variation;

5. Figure 18: hourly and daily leverage effects using bivariate models, realized volatility and bipower variation;

6. Figure 19: instantaneous causality and dependence between daily returns and volatility using bivariate models, realized volatility and bipower variation;

7. Figure 20: causality measures between daily implied volatility (IV) [or variance risk premium $IV - RV$] and daily realized volatility (RV), using trivariate VAR models for (r, RV, IV) and $(r, RV, IV - RV)$;

8. Figure 21: volatility feedback effects, with implied volatility as auxiliary variable [trivariate model $(r,\ RV,\ IV)$] and without implied volatility [bivariate model $(r,\ RV)$];

9. Figure 22: other volatility feedback effects using variance risk premium $(IV - RV)$ and the impact of $(RV,\ IV - RV)$ on returns;

10. Figure 23: leverage effects in the presence of implied volatility [trivariate models (r, RV, IV) and $(r, RV, IV - RV)$] and in the absence of implied volatility [bivariate model (r, RV)];

11. Figure 24: causality measures of the impact of bad return news on volatility, using 5 estimators of the conditional mean return $(m = 15,\ 30,\ 90,\ 120,\ 240)$, realized volatility $[\ln(RV)]$ and bipower variation $[\ln(BV)]$;

12. Figure 25: causality measures of the impact of bad and good volatility news [positive and negative variance risk premium] on returns.

Table 9. Hourly and daily volatility feedback effects

Hourly volatility feedback effects using $\ln(RV)$

$C(\ln(RV) \underset{h}{\rightarrow} r)$	$h = 1$	$h = 2$	$h = 3$	$h = 4$
Point estimate	0.00016	0.00014	0.00012	0.00012
95% Bootstrap interval	$[0.0000,\ 0.0.0006]$	$[0.0000,\ 0.0005$	$[0.0000,\ 0.0.0004]$	$[0.0000,\ 0.0.0004]$

Hourly volatility feedback effects using $\ln(BV)$

$C(\ln(BV) \underset{h}{\rightarrow} r)$	$h = 1$	$h = 2$	$h = 3$	$h = 4$
Point estimate	0.00022	0.00020	0.00019	0.00015
95% Bootstrap interval	$[0.0000,\ 0.0006]$	$[0.0000,\ 0.0006]$	$[0.0000,\ 0.0005]$	$[0.0000, 0.0005]$

Daily volatility feedback effects using $\ln(RV)$

$C(\ln(RV) \underset{h}{\rightarrow} r)$	$h = 1$	$h = 2$	$h = 3$	$h = 4$
Point estimate	0.0019	0.0019	0.0019	0.0011
95% Bootstrap interval	$[0.0000,\ 0.0056]$	$[0.0000,\ 0.0056]$	$[0.0000,\ 0.0056]$	$[0.0000,\ 0.0038]$

Daily volatility feedback effects using $\ln(BV)$

$C(\ln(BV) \underset{h}{\rightarrow} r)$	$h = 1$	$h = 2$	$h = 3$	$h = 4$
Point estimate	0.0017	0.0017	0.0016	0.0011
95% Bootstrap interval	$[0.0000,\ 0.0053]$	$[0.0000,\ 0.0049]$	$[0.0000,\ 0.0048]$	$[0.0000,\ 0.0038]$

Note: This table summarizes the estimation results of causality measures from hourly realized volatility $[\ln(RV)]$ to hourly returns (r), hourly bipower variation $[\ln(BV)]$ to hourly returns, daily realized volatility to daily returns, and daily bipower variation to daily returns, respectively. The second row in each small table gives the point estimate of the causality measures at horizons $h = 1, ..., 4$. The third row gives the 95% corresponding percentile bootstrap (Fixed-design wild bootstrap) interval.

Table 10. Measuring the impact of good return news on volatility using $\ln(RV)$ [centered positive returns]

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{15}\sum_{j=1}^{15} r_{t+1-j}$$

$C(er^+ \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0007	0.0007	0.0007	0.0004
95% Percentile bootstrap interval	$[0.0002, 0.0058]$	$[0.0002, 0.0062]$	$[0.0001, 0.0057]$	$[0.0000, 0.0057]$

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{30}\sum_{j=1}^{30} r_{t+1-j}$$

$C(er^+ \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0010	0.0007	0.0007	0.0005
95% Percentile bootstrap interval	$[0.0003, 0.0070]$	$[0.0003, 0.0068]$	$[0.0002, 0.0069]$	$[0.0001, 0.0060]$

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{90}\sum_{j=1}^{90} r_{t+1-j}$$

$C(er^+ \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0013	0.0008	0.0008	0.0008
95% Percentile bootstrap interval	$[0.0003, 0.0063]$	$[0.0002, 0.0038]$	$[0.0002, 0.0040]$	$[0.0001, 0.0035]$

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{120}\sum_{j=1}^{120} r_{t+1-j}$$

$C(er^+ \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0011	0.00076	0.00072	0.00074
95% Percentile bootstrap interval	$[0.0002, 0.0064]$	$[0.0002, 0.0067]$	$[0.0002, 0.0056]$	$[0.0001, 0.0051]$

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{240}\sum_{j=1}^{240} r_{t+1-j}$$

$C(er^+ \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0011	0.0006	0.0006	0.0007
95% Percentile bootstrap interval	$[0.0003, 0.0070]$	$[0.0002, 0.0062]$	$[0.0003, 0.0058]$	$[0.0001, 0.0050]$

Note: This table summarizes the estimation results of causality measures from centered positive returns (er^+) to realized volatility $[\ln(RV)]$ using five estimators of the conditional mean, for $m = 15,\ 30,\ 90,\ 120,\ 240$. In each of the five small tables, the second row gives the point estimate of the causality measures at horizons $h = 1, ..., 4$. The third row gives the 95% corresponding percentile bootstrap interval.

Table 11. Measuring the impact of good return news on volatility using $\ln(BV)$ [centered positive returns]

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{15}\sum_{j=1}^{15} r_{t+1-j}$$

$C(er^{+} \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0008	0.0008	0.0006	0.0006
95% Percentile bootstrap interval	$[0.0002, 0.0063]$	$[0.0001, 0.0061]$	$[0.0001, 0.0059]$	$[0.0000, 0.0058]$

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{30}\sum_{j=1}^{30} r_{t+1-j}$$

$C(er^{+} \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0012	0.0007	0.0007	0.0007
95% Percentile bootstrap interval	$[0.0004, 0.0072]$	$[0.0002, 0.0071]$	$[0.0001, 0.0067]$	$[0.0000, 0.0061]$

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{90}\sum_{j=1}^{90} r_{t+1-j}$$

$C(er^{+} \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0018	0.0009	0.0008	0.0010
95% Percentile bootstrap interval	$[0.0004, 0.0065]$	$[0.0002, 0.0044]$	$[0.0001, 0.0041]$	$[0.0001, 0.0042]$

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{120}\sum_{j=1}^{120} r_{t+1-j}$$

$C(er^{+} \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0016	0.0008	0.0007	0.0009
95% Percentile bootstrap interval	$[0.0003, 0.0076]$	$[0.0002, 0.0068]$	$[0.0001, 0.0063]$	$[0.0000, 0.0065]$

$$\widehat{\mathsf{E}_t(r_{t+1})} = \frac{1}{240}\sum_{j=1}^{240} r_{t+1-j}$$

$C(er^{+} \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0015	0.0007	0.0006	0.0008
95% Percentile bootstrap interval	$[0.0004, 0.0071]$	$[0.0002, 0.0065]$	$[0.0001, 0.0060]$	$[0.0000, 0.0058]$

Note: This table summarizes the estimation results of causality measures from centered positive returns (er^{+}) to bipower variation [$\ln(BV)$] using five estimators of the conditional mean, for $m = 15,\ 30,\ 90,\ 120,\ 240$. In each of the five small tables, the second row gives the point estimate of the causality measures at horizons $h = 1, ..., 4$. The third row gives the 95% corresponding percentile bootstrap interval.

Table 12. Measuring the impact of good return news on volatility [uncentered positive returns]

using $\ln(RV)$

$C(r^{+} \underset{h}{\rightarrow} \ln(RV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0027	0.0012	0.0008	0.0009
95% Percentile bootstrap interval	$[0.0000,\ 0.0.0057]$	$[0.0000,\ 0.0046]$	$[0.0000,\ 0.0042]$	$[0.0000,\ 0.0040]$

using $\ln(BV)$

$C(r^{+} \underset{h}{\rightarrow} \ln(BV))$	$h=1$	$h=2$	$h=3$	$h=4$
Point estimate	0.0035	0.0013	0.0008	0.0010
95% Percentile bootstrap interval	$[0.0000,\ 0.0063]$	$[0.0000,\ 0.0051]$	$[0.0000,\ 0.0047]$	$[0.0000, 0.0044]$

Note: This table summarizes the estimation results of causality measures from uncentered positive returns (r^{+}) to realized volatility $[\ln(RV)]$ [bipower variation $\ln(BV)$]. The second row of each small table gives the point estimate of the causality measures at horizons $h = 1, \ldots, 4$. The third row gives the 95% corresponding percentile bootstrap interval.

Figure 18. Leverage effects in hourly and daily data, using bivariate models for $(r, \ln(RV))$ and $(r, \ln(BV))$. January 1988 to December 2005.

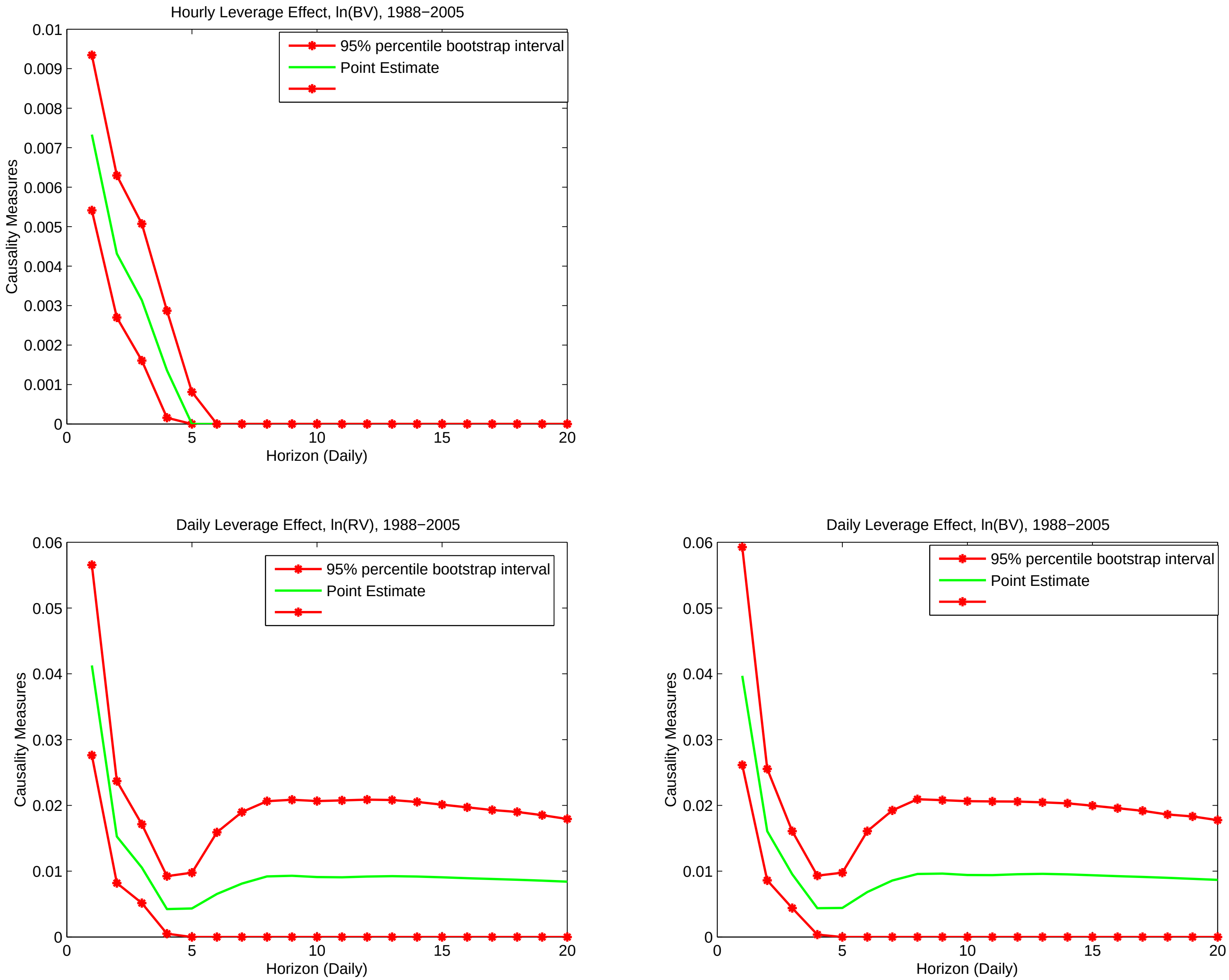


Figure 19. Instantaneous causality and dependence between daily returns and volatility using bivariate models for $(r, \ln(RV))$ and $(r, \ln(BV))$. January 1988 to December 2005.

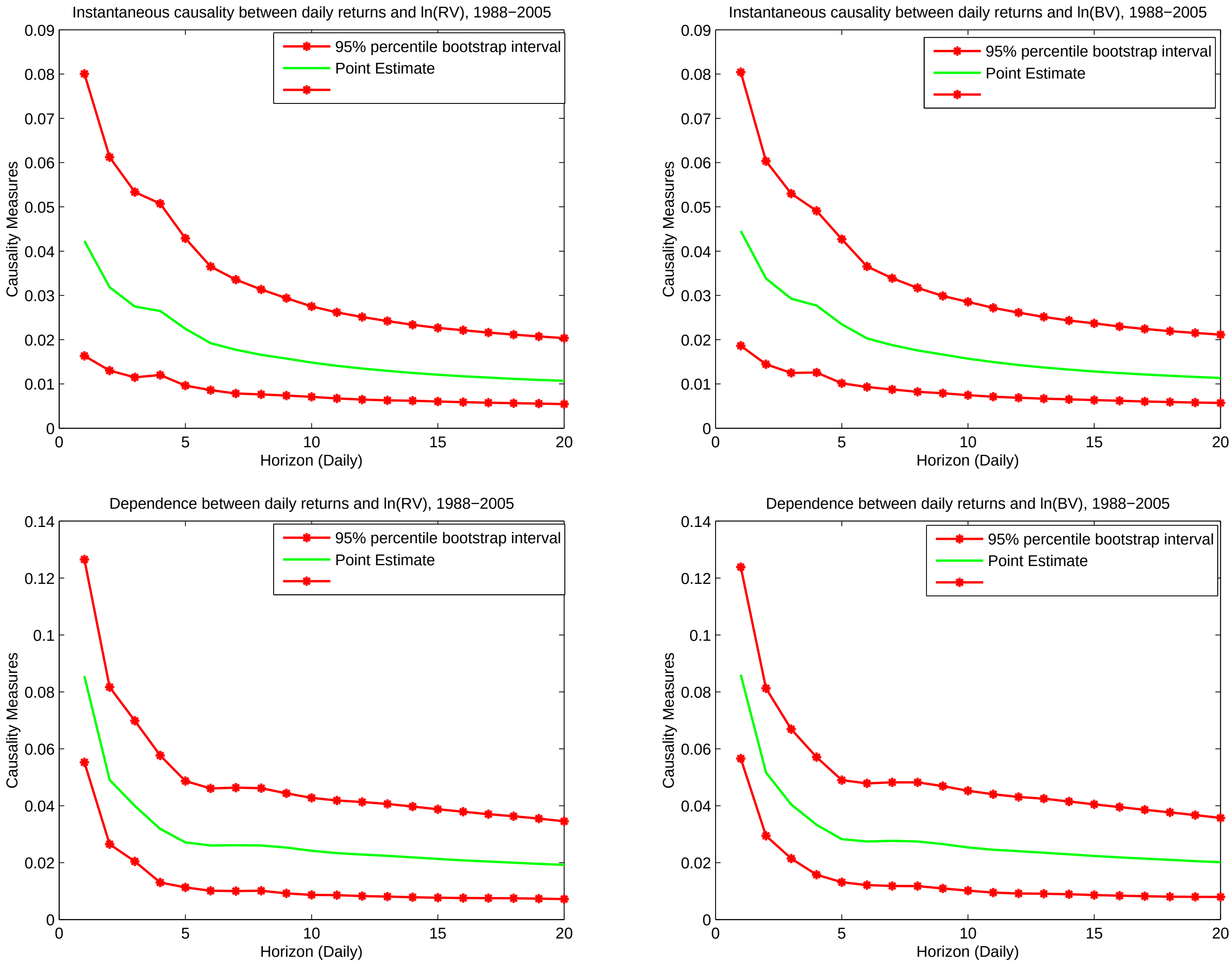


Figure 20. Causality measures between implied volatility (IV) [or variance risk premium $IV - RV$] and realized volatility (RV), using trivariate VAR models for (r, RV, IV) and $(r, RV, IV - RV)$. January 1996 to December 2005.

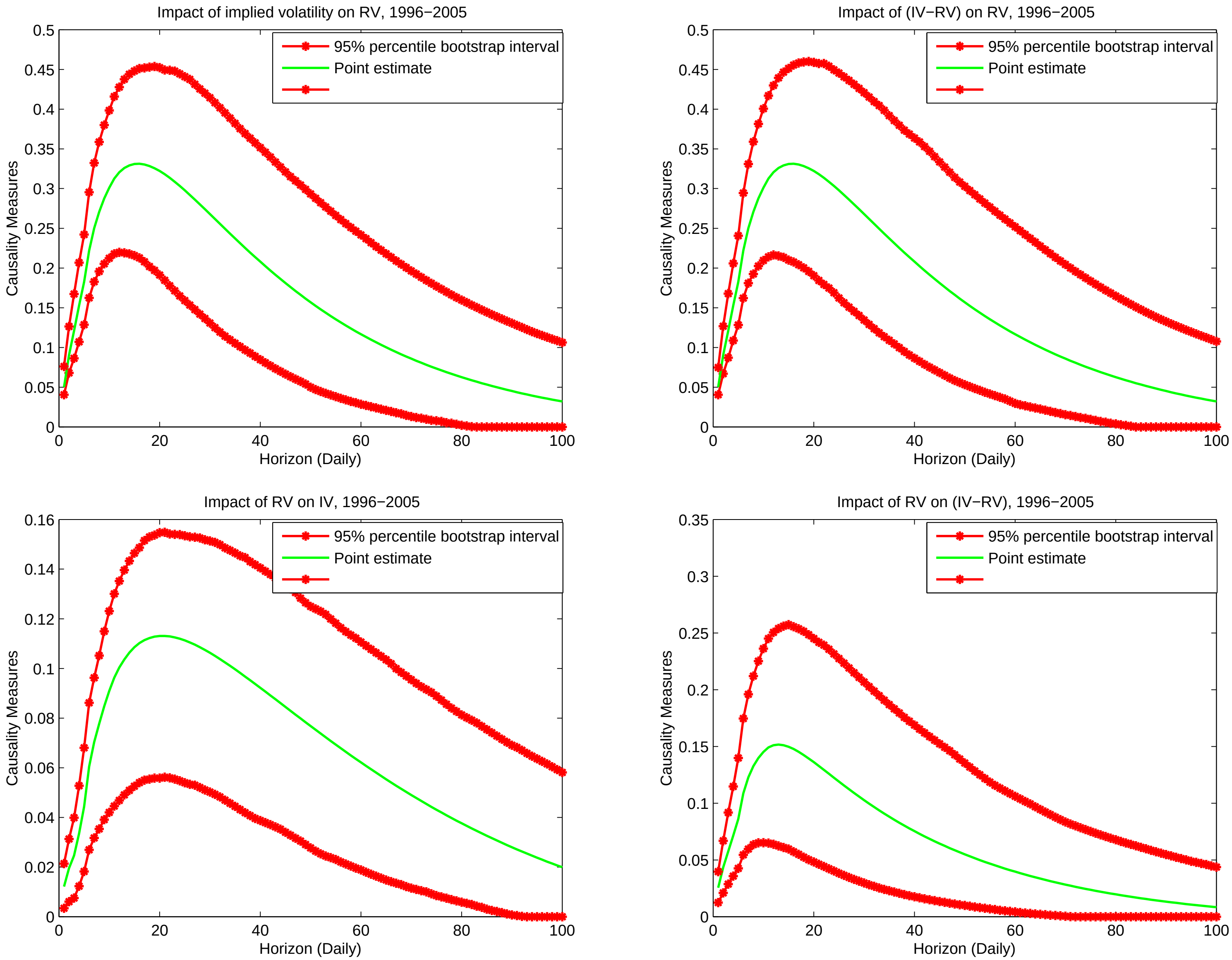


Figure 21. Volatility feedback effects, with implied volatility as auxiliary variable [trivariate model $(r,\ RV,\ IV)$] and without implied volatility [bivariate model $(r,\ RV)$]. January 1996 to December 2005.

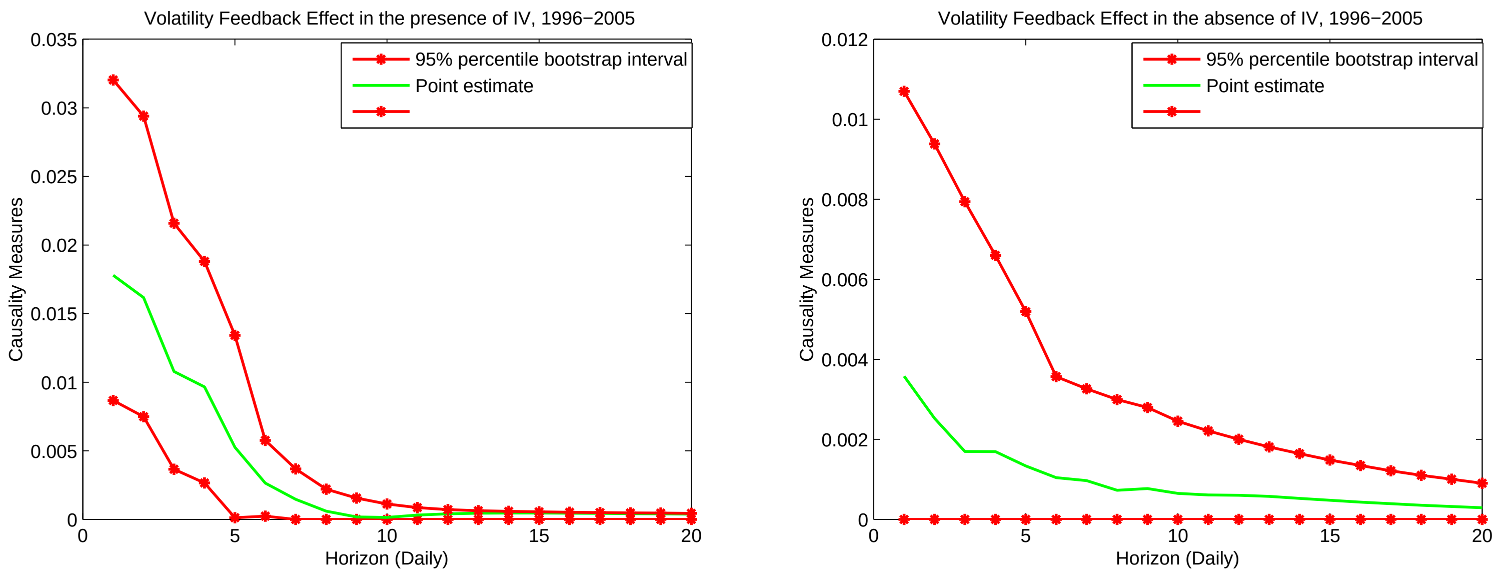


Figure 22. Other volatility feedback effects using variance risk premium $(IV - RV)$ and impact of $(RV, IV - RV)$ on returns. January 1996 to December 2005.

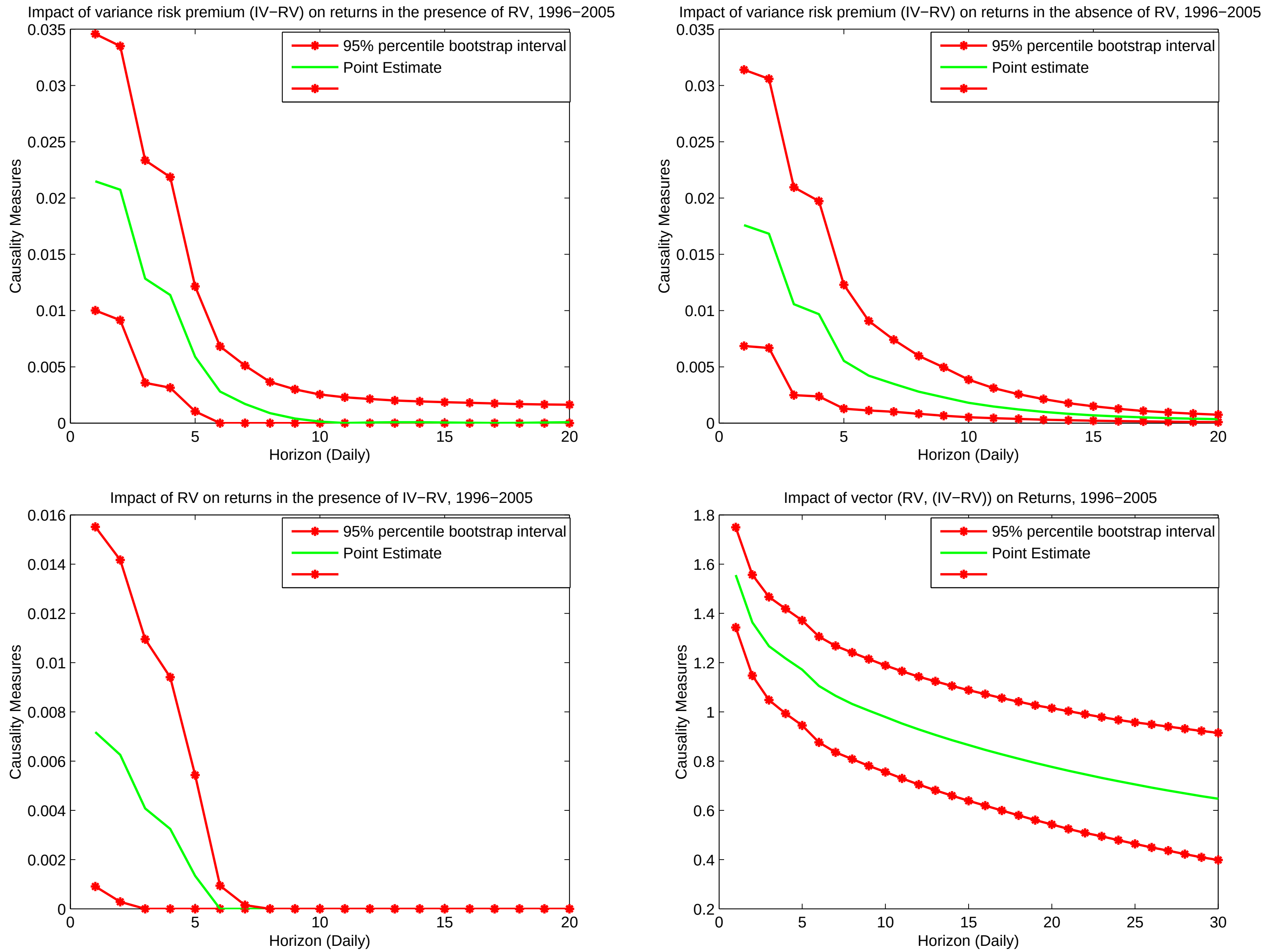
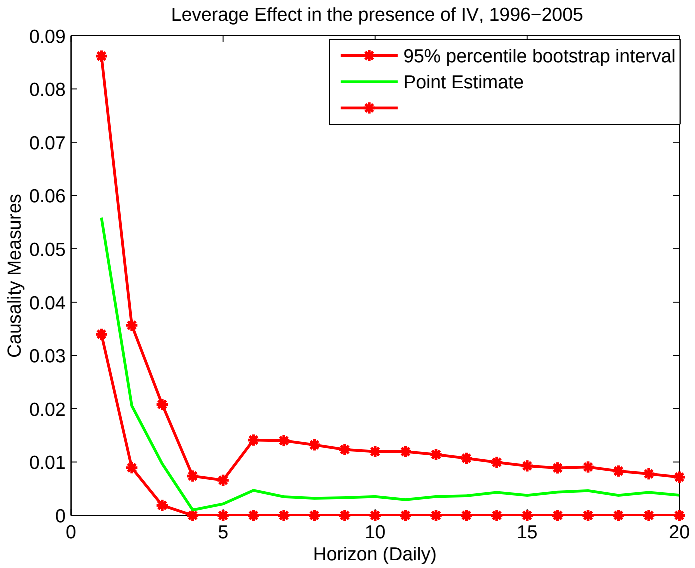
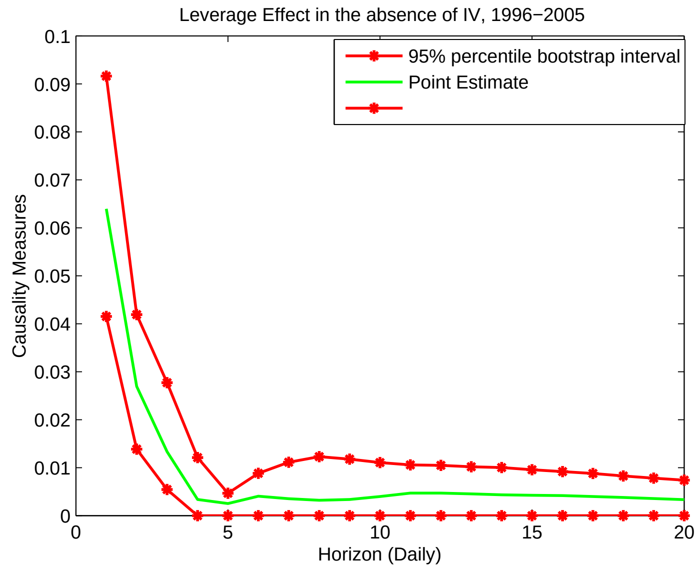


Figure 23. Leverage effects, with implied volatility as auxiliary variable [trivariate model $(r,\ RV,\ IV)$ or $(r,\ RV,\ IV - RV)$] and without implied volatility [bivariate model $(r,\ RV)$]. January 1996 to December 2005.





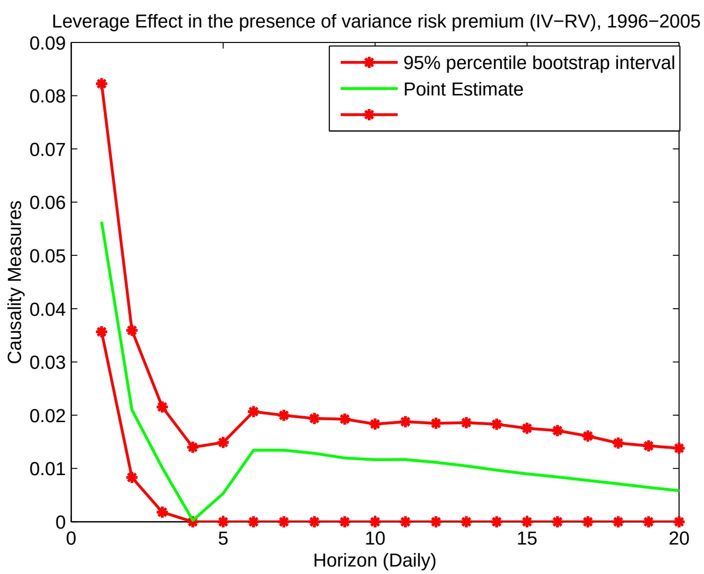


Figure 24. Causality measures of the impact of bad return news on volatility, using 5 estimators of the conditional mean return ($m = 15, 30, 90, 120, 240$), realized volatility $[\ln(RV)]$ and bipower variation $[\ln(BV)]$. January 1988 to December 2005.

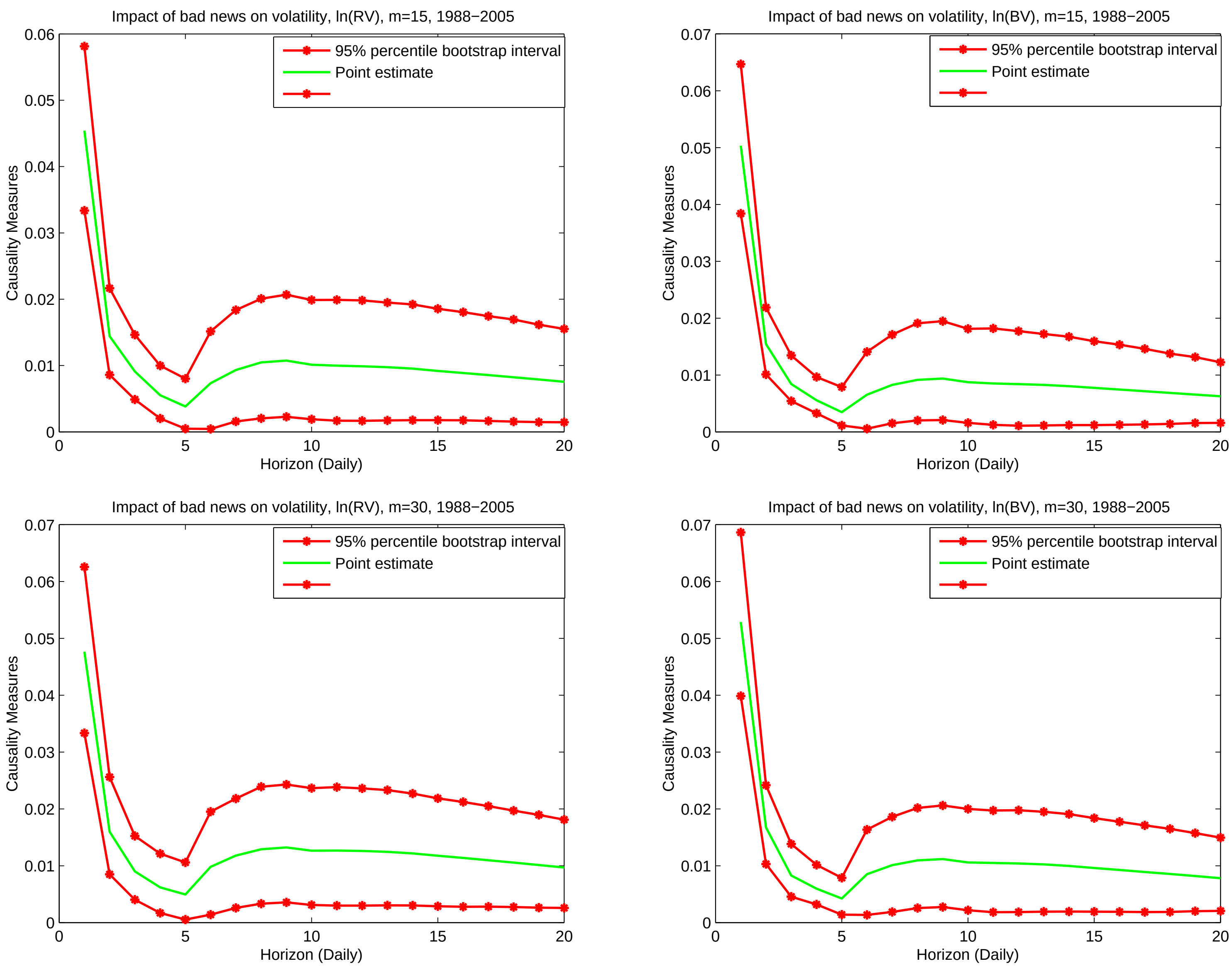


Figure 24 (continued). Causality measures of the impact of bad return news on volatility, using 5 estimators of the conditional mean $(m = 15, 30, 90, 120, 240)$, realized volatility $[\ln(RV)]$ and bipower variation $[\ln(BV)]$. January 1988 to December 2005.

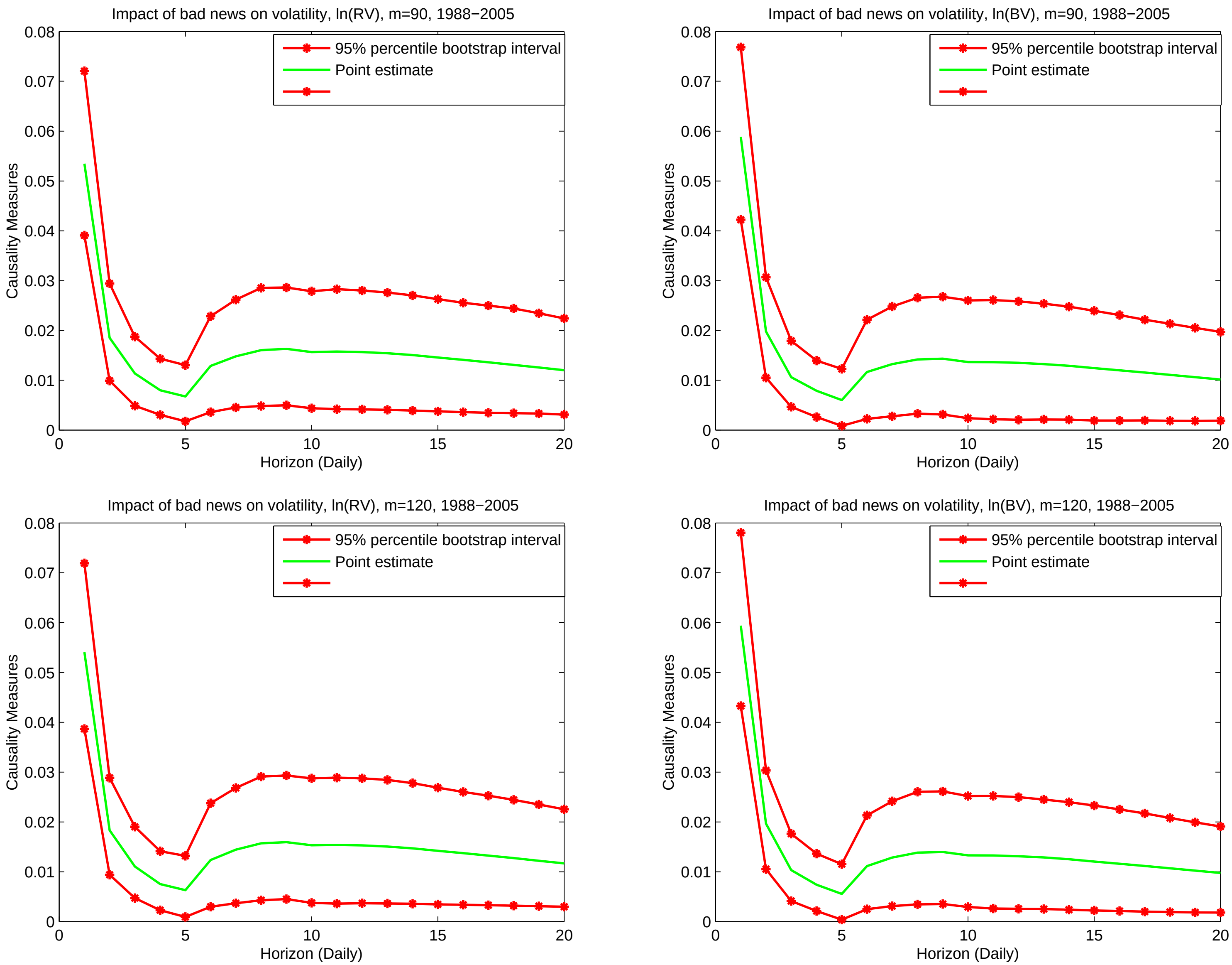


Figure 24 (continued). Causality measures of the impact of bad return news on volatility, using 5 estimators of the conditional mean $(m = 15, 30, 90, 120, 240)$, realized volatility $[\ln(RV)]$ and bipower variation $[\ln(BV)]$. January 1988 to December 2005.

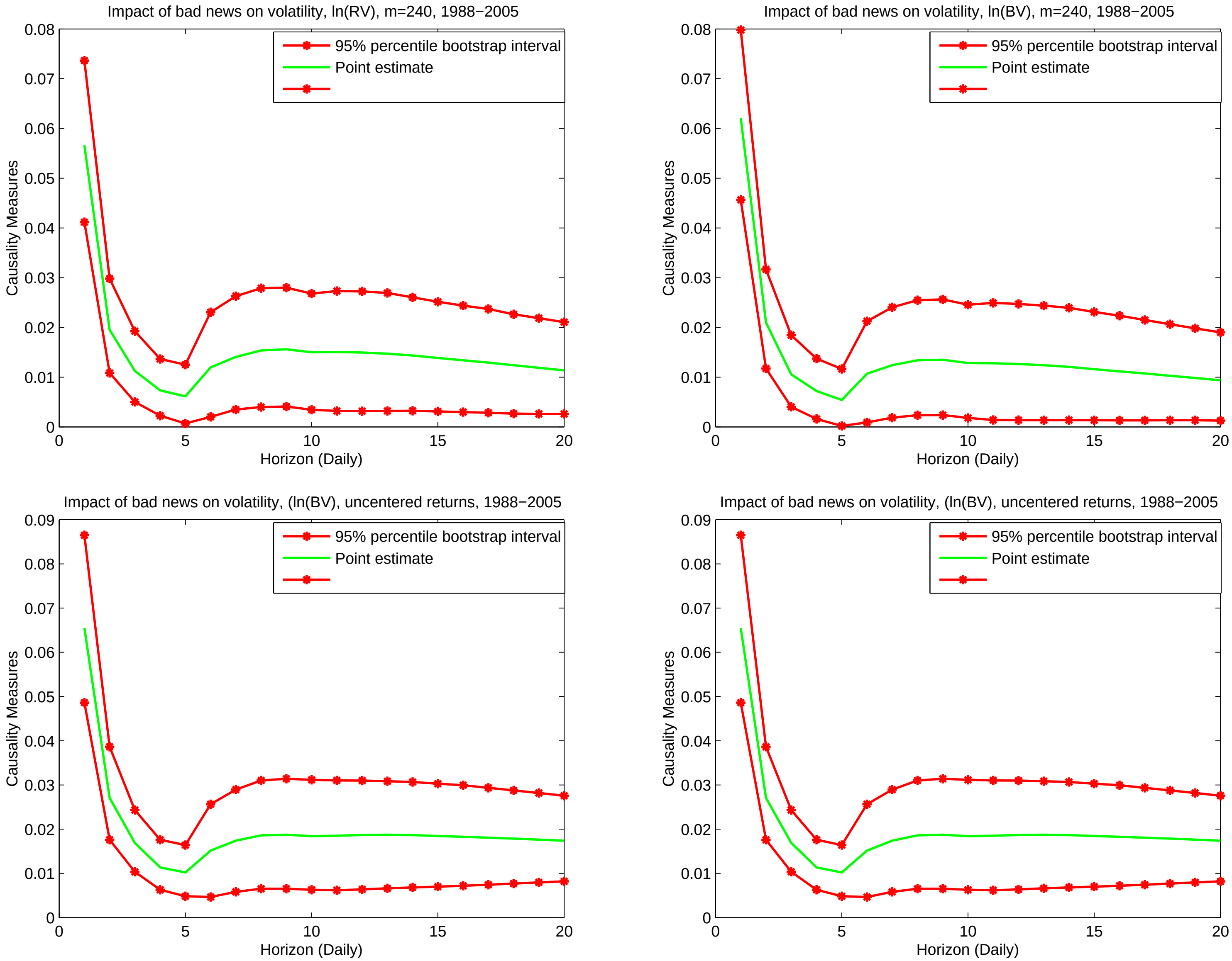
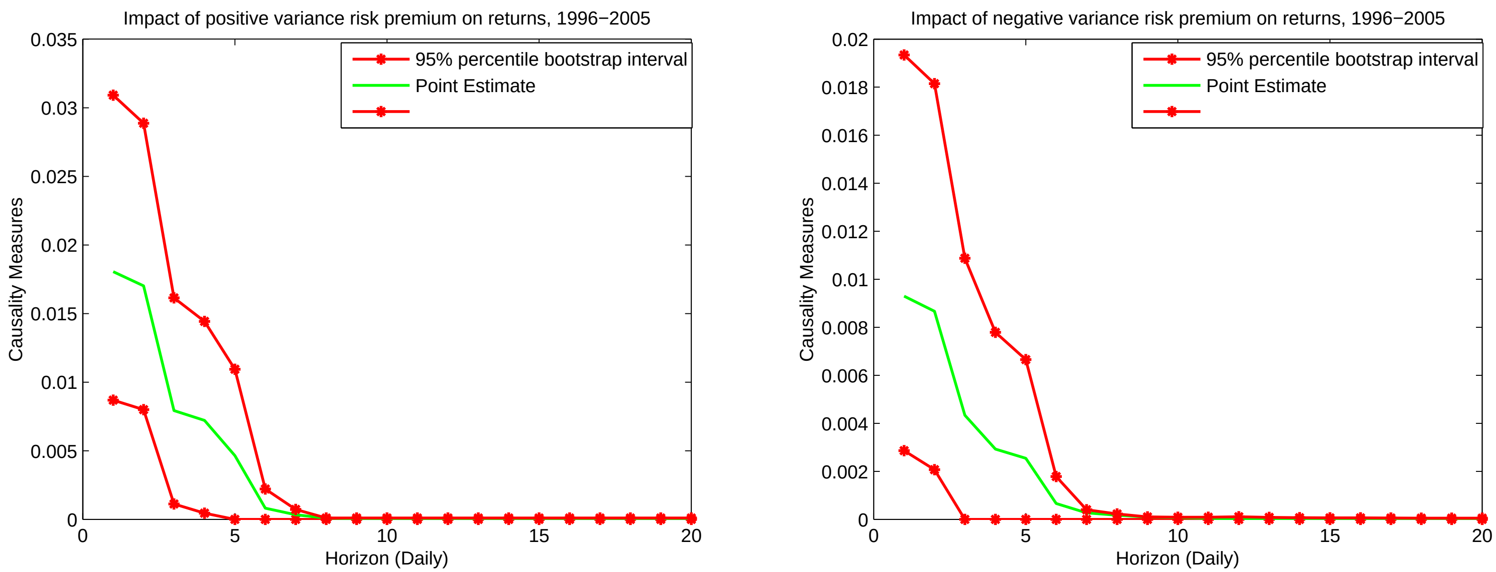


Figure 25. Causality measures of the impact of positive and negative variance risk premium on returns. January 1996 to December 2005.



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